UV Radiation Resistance and Solar Blindness of CsI and KBr Photocathodes

A. S. Tremsin and O. H. W. Siegmund

***Abstract*—A detailed study of the stability of CsI and KBr photocathodes under UV irradiation is presented. UV quantum efficiency degradation was found to be more pronounced at lower illumination intensity for the same accumulated dose and illumination wavelength. For an equal number of extracted photoelectrons in-band UV exposure led to a larger sensitivity decay as compared to out-of-band illumination. The angle of radiation incidence was not important for the UV sensitivity degradation, while changes of visible light rejection (i.e., degradation of solar blindness) did depend on the incidence angle: the photocathodes illuminated at normal incidence were activated much faster than the films irradiated at grazing angle. We found that the increase of visible sensitivity can be characterized by the total accumulated dose and is independent of irradiation flux during UV activation. We also observed that heat annealing substantially improves the visible light rejection of C–sI photocathodes.**

***Index Terms*—Detectors, photocathodes, sensitivity, stability.**

I. Introduction

THE SENSITIVITY of imaging and spectroscopic detectors is often increased by photocathodes optimized for a particular wavelength range. Alkali halide photocathodes are currently widely used in various UV detecting devices [1]–[6] due to their high efficiency and relative stability under air exposure. Photoconversion efficiency is a crucial parameter determining the performance of the entire detecting device. At the same time, the stability of the photocathode sensitivity is essential for many applications where long operation time is required or large doses of UV irradiation are involved. The stability of UV quantum efficiency (QE) of alkali halide photocathodes under UV illumination was studied in recent papers [5], [7]–[14]. The current detailed study of the response of CsI and KBr photocathodes was performed with thin films of these materials deposited directly on the front surface of microchannel plates (opaque photocathodes). The ability of microchannel plates to detect almost every single photoelectron produced by the photocathodes allowed us to substantially extend the previous investigations with planar reflective photocathodes [11], where the sensitivity was limited by an electrometer measuring photocurrent from the samples. We have measured the stability of photoconversion efficiency in the UV range as a function of radiation wavelength, angle of incidence, flux rate, and dose (Section III). In addition, the dependence of visible light rejection (solar blindness) on the flux rate, wavelength, and angle of radiation incidence was determined (Section IV). We have also considered the influence of photocathode heat treatment on the efficiency of visible light rejection.

II. Experimental Setup

The stability of CsI and KBr photocathodes was studied with thin films of these materials deposited directly on the input surface of microchannel plates (MCPs), which were heated to ~90 °C before and during deposition. A quartz lamp positioned in the evaporation vessel was used to heat the MCPs. A high purity (99.999%) CsI or KBr material was evaporated at a rate of $\leq$20 Å s^{-1} in a vacuum system at 10^{-6} torr. All films were ~9000-Å thick. After deposition all photocathodes were 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 1×10^{-6} torr.

The detector used in the present study consisted of a Z-stack of microchannel plates 33 mm in diameter with 12.5-μm pores on 15-μm centers, 80:1 length-to-diameter ratio, with resistance of ~30 MΩ, and a pore bias of 13°. The voltage across the MCP stack was about 3200 V, corresponding to a detector modal gain of about 10^7.

Monochromatic UV radiation (256–2000 Å) 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, and PIN UV-100[1] photodiodes. A 150-W white light source with a light guide in combination with a set of filters was used for the visible light illumination. 1849- and 2537-Å illumination was provided by a combination of a mercury vapor penray lamp and UV filters from Acton Re Corporation (1878 and 2545-Å filters with peak transmissions of 17 and 12.5 % and bandwidths of 219 and 110 Å, respectively).

A 90% transmissive nickel mesh was installed ~5 mm in front of the MCP; see Fig. 1. Variation of the mesh potential allowed us to separately investigate the photocathode stability inside the MCP pores and on the interchannel web area. Negative biasing of the mesh relative to the MCP input provided the electric field, which repelled the photoelectrons emitted from the interchannel web area into the MCP pores. Changing the

Manuscript received December 5, 2000; revised February 21, 2001. This work was supported by NASA under Grant NAG5-3913.

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Publisher Item Identifier S 0018-9499(01)04921-8.

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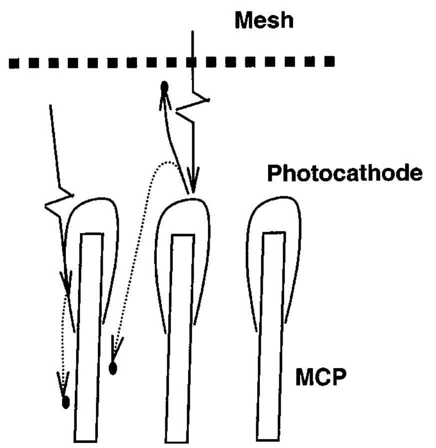

Fig. 1. Schematic diagram of an opaque photocathode deposited on a microchannel plate (not to scale). The photocathode inside microchannel pores irradiated at grazing angles, while the interchannel web area film irradiated at normal incidence.

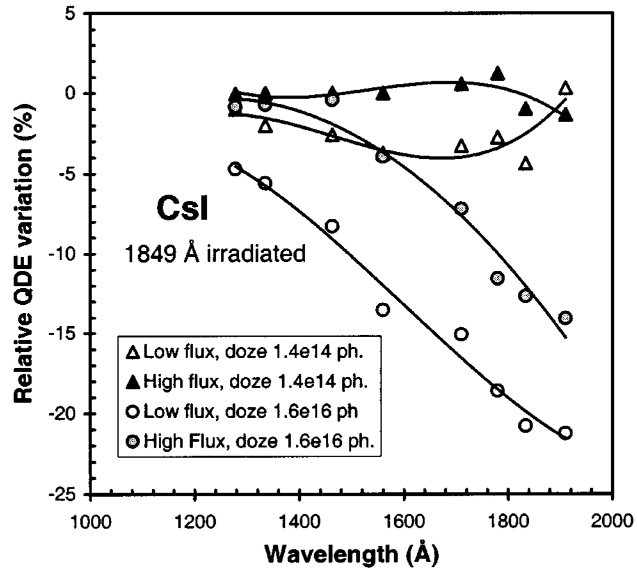

Fig. 2. Relative variation of the UV quantum detection efficiency (QDE) of CsI photocathode induced by 1849-Å irradiation of different intensity, normalized to initial QDE values. Triangles—accumulated dose 1.4×10^{14} photons cm^{-2}, flux rates 2.6×10^{9} and 2.8×10^{10} photons cm^{-2} s^{-1}. Circles—dose 1.6×10^{16}, flux rates 2.8×10^{11} and 10^{12} photons cm^{-2} s^{-1}. Lower fluxes lead to a larger sensitivity degradation.

mesh bias to positive, as related to the MCP, eliminated the web photoelectron contribution to the photon counting.

III. Sensitivity Degradation Under UV Irradiation

It was recently observed that alkali halide photocathodes exhibit some sensitivity degradation after exposure to a relatively large dose of UV irradiation. In our previous study [11] we have already shown that heating of the CsI photocathodes not only increases their UV and soft X-ray sensitivity (as reported by Breskin *et al.* [8], [15] and Lees *et al.* [16]), but also substantially improves the stability of their response under UV exposure. In the present work we elaborate on the aging of CsI and KBr photocathodes and consider the importance of radiation wavelength, flux rate, and angle of incidence for the QE degradation. We also investigated the influence of the electric field on the photocathode degradation. We found that when the photocathode substrate was positively biased relative to the mesh positioned in front of the sample the UV sensitivity of CsI photocathode did not decay as fast as in the case when the photocathode substrate was biased negatively [17]. Thus the presence of the negatively biased repelling mesh in front of many MCP detectors not only improves the detection sensitivity, but also reduces the photocathode sensitivity degradation.

A. QE Degradation Versus Irradiation Flux Rate

It is important to determine whether the QE degradation for a specific wavelength irradiation is determined solely by the accumulated dose or is also dependent on the time during which that dose was accumulated. A CsI photocathode was exposed to 1849-Å photons with flux rates differing by a factor of $\sim$10, while the dose was equal for both “slow” and “fast” exposures.

Fig. 2 shows the relative QE variation after these exposures. It is clearly seen from the difference in sensitivity degradation that the flux rate is an essential parameter for the processes taking place during photocathode aging during UV exposures: for a fixed dose slower irradiation leads to a substantially larger sensitivity degradation.

The exact mechanism of photocathode aging is not known at the present time. One of the possible explanations can be formation of additional traps for photoelectrons (e.g., color centers). If coloration of UV irradiated photocathodes can explain the UV aging phenomenon, then the importance of the flux rate can be attributed to the rate of color center recombination. At lower fluxes the reduction of concentration by diffusion is more pronounced and the recombination rate is lower than at higher fluxes, leading to a larger concentration of color centers after irradiation with equal doses.

B. Aging at Different Wavelengths

Two different spectral lines from a mercury vapor penray lamp were used in our aging studies: 1849- (in-band) and 2537-Å (out-of-band) illumination. In the case of CsI the dose of 2537-Å exposure was chosen so that the number of electrons extracted from the photocathode and the rate of photoelectron production were approximately equal at both 1849- and 2537-Å exposures (filled triangles and circles in Fig. 3, respectively).

We observed that shorter (in-band) illumination led to much stronger QE degradation, not only for equal doses but also for equal number of extracted photoelectrons. The latter fact suggests that out-of-band illumination is probably preferable for MCP detector preconditioning (scrubbing) for gain stabilization. We also observed that the QE degradation is likely to be a nonlinear function with accumulated dose since the sensitivity was reduced by a factor of 1.6 after the dose was increased by a factor of two (open and filled triangles in Fig. 3). The same effect of nonlinear dependence of sensitivity degradation on a dose was observed by Singh *et al.* [14].

C. Importance of Irradiation Angle

Variation of potential on the repelling mesh in front of the MCPs allowed us to measure the response of the photocathode inside the pores (irradiated at grazing angle) and the photo-

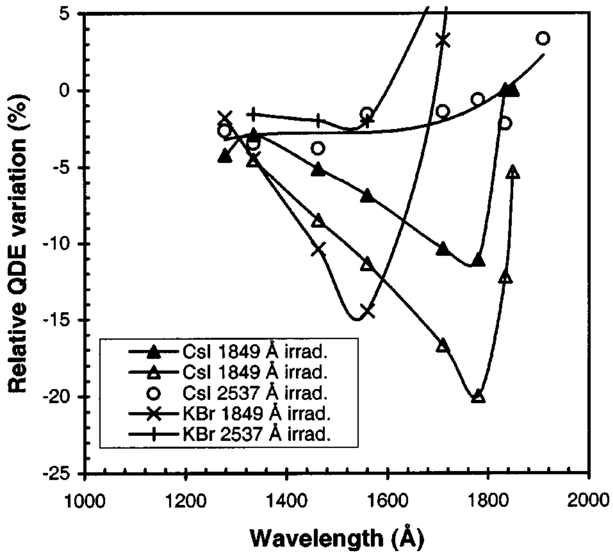

Fig. 3. Relative variation of the UV quantum detection efficiency of CsI and KBr photocathode induced by 1849- and 2537-Å irradiation normalized to initial QDE values. CsI: triangles—accumulated dose 3.4×10^{13} and 7.2×10^{13} photons cm^{-2}, flux rate 1.5×10^{8} photons cm^{-2} s^{-1}; circles—dose 6.7×10^{16} accumulated at flux rate of 2.7×10^{11} photons cm^{-2} s^{-1}. Crosses—KBr photocathode irradiated with 1849 and 2537 Å photons with doses of 10^{14} and 10^{16} photons cm^{-2} and flux rates of 10^{10} and 2.7×10^{11} photons cm^{-2} s^{-1}, respectively.

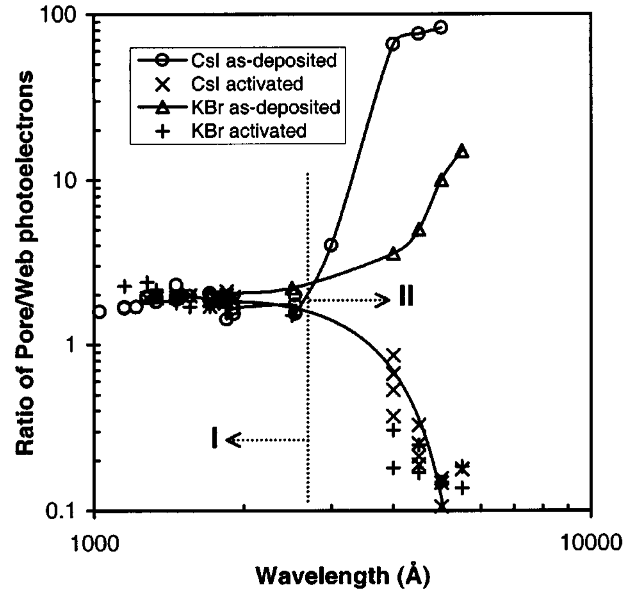

Fig. 4. The ratio of pore-to-web photocathode efficiency measured before and after irradiation with 1849-Å photons (accumulated dose of about 10^{14} photons cm^{-2} s^{-1}). After UV exposure the value of the ratio remains constant within UV range (area I). Web contribution dramatically increases in the visible part of spectrum (area II), indicating that degradation of UV efficiency is independent of angle of radiation incidence, while activation of visible sensitivity does strongly depend on angle.

cathode in the interchannel web area (irradiated at normal incidence) separately; see Fig. 1. Only these two extreme angles were investigated in our study and both aging illumination and QE measurements were performed at the same angle of radiation incidence.

Fig. 4 represents the ratio of pore-to-web efficiency (the ratio of photoelectrons number originated at pore photocathode to the number of photoelectrons from the web area). In the UV spectral range that ratio is equal to the same constant before and after the photocathode aging. The latter fact indicates that the sensitivity degradation is equal for both pore and web area photocathodes. Thus the angle of radiation incidence is not an important parameter for the aging processes, at least in the case when UV irradiation and QE measurements are performed at the same angle of radiation incidence. Dramatic change of the pore/web ratio after UV exposure in visible spectral range is discussed in the next section.

IV. Visible Light Rejection

The very low sensitivity of alkali halide photocathodes to visible light is a crucial parameter for some applications where noise from scattered visible light might impair the detector response to weak UV signals. It was found recently that sensitivity of CsI and KBr photocathodes in the visible range can be increased by UV exposure [4], [18] and we have observed that the visible QE increase can be as much as four and seven orders of magnitude for CsI and KBr, respectively [13]; see Fig. 5. We use term “photocathode activation” for the processes of UV illumination during which sensitivity of the photocathode in visible spectral range is increased. The rejection of visible light can be easily restored by subsequent irradiation of the photocathode with visible light and the rate of the deactivation was found to be on the order of minutes, although complete deactivation requires a relatively prolonged exposure [13].

The importance of the angle of radiation incidence for the activation was studied indirectly again by measuring the activation of the photocathode in pores and on the interchannel web area. As clearly seen from Fig. 4, before the photocathodes were activated most of the photoelectrons in the visible part of the spectrum originated from the film deposited inside pores (irradiated at grazing incidence), while after UV irradiation of the same photocathodes the photoelectrons were emitted predominantly from the web area (illuminated at normal incidence). Therefore, we conclude that activation of the photocathode deposited on the web area was much stronger and the angle of irradiation incidence is an important parameter for the activation processes.

A. Activation Versus Irradiation Flux Rate

Similar to the aging measurements described above, the activation of a KBr photocathode was measured after equal doses of irradiation, while the illumination intensity was changed between different activations. Fig. 6 represents the results of these measurements with activation performed with 1710- and 1849-Å photons. Each curve in this figure corresponds to a cross section through images obtained at 5500 Å with full flood illumination on a detector containing a photocathode activated over a 6-mm-wide spot. The height of the peaks in Fig. 6 shows the level of photocathode activation.

Equal levels of activation at a given wavelength as seen in Fig. 6 indicate that flux rate is not an essential parameter for the increase of visible sensitivity by UV exposure and the accumulated dose solely determines the level of activation for a particular irradiation wavelength.

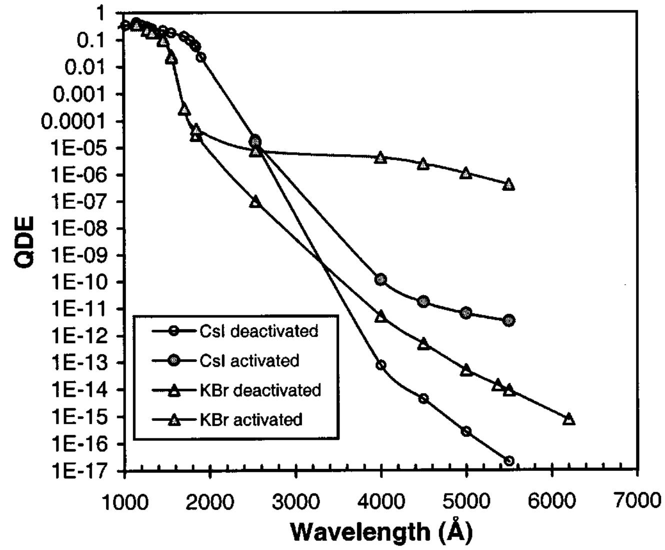

Fig. 5. The quantum detection efficiency as a function of wavelength for as-deposited and UV-irradiated (activated) CsI and KBr opaque photocathodes. The total dose of UV irradiation was 5×10^{13} and 10^{14} photons cm^{-2} at 1849 Å for CsI and KBr, respectively (corresponding flux rates of 10^{8} and 10^{10} photons s^{-1} cm^{-2}).

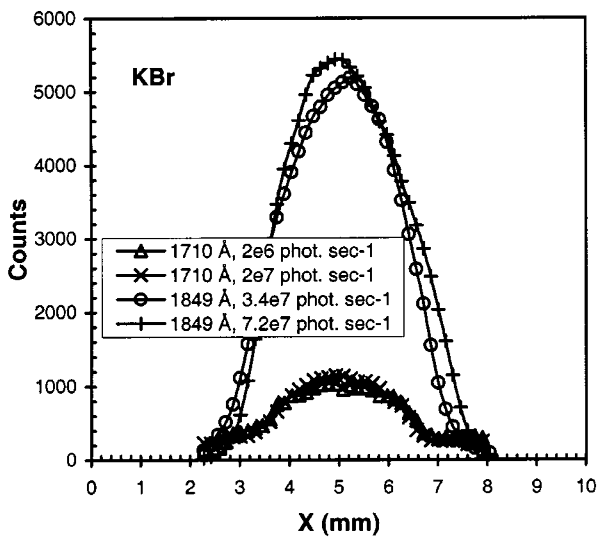

Fig. 6. Cross sections through images obtained at 5500 Å illumination with KBr photocathodes activated by 1710- and 1849-Å photons at different fluxes but equal accumulated dose at each wavelength. 1710-Å activation: dose 5×10^{8} photons cm^{-2} at flux rates of 2×10^{6} and 2×10^{7} photons cm^{-2} s^{-1}. 1849 Å activation: dose 1.4×10^{10} photons cm^{-2} at flux rates of 3.4×10^{7} and 7.2×10^{7} photons cm^{-2} s^{-1}.

B. Activation Versus Irradiation Wavelength

Cross sections through images obtained with detector activated with different wavelengths are shown in Fig. 7. Although the dose of UV irradiation was not equal for all of the UV exposure (due to the limited range of brightness of the source used in our measurements), we still can conclude that the activation is likely to be the most effective with irradiation wavelengths below the sensitivity cutoff. Illumination of the photocathode with 1849-Å photons led to the largest increase of the visible sensitivity in our measurements. At the same time, activation of the KBr photocathode with out-of-band (2537 Å) UV illumination was almost negligible.

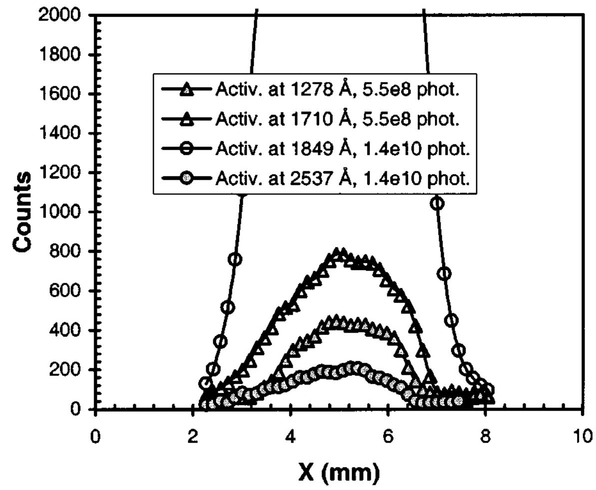

Fig. 7. Cross sections through images obtained at 5500-Å illumination with KBr photocathodes activated by different wavelengths. Flux rate of 1.8×10^{6} photons cm^{-2} s^{-1} and accumulated dose of 5.5×10^{8} photons cm^{-2} for 1278- and 1710-Å activation. Flux rate of 3.3×10^{7} photons cm^{-2} s^{-1} and accumulated dose of 1.4×10^{10} photons cm^{-2} for 1849- and 2537-Å activation.

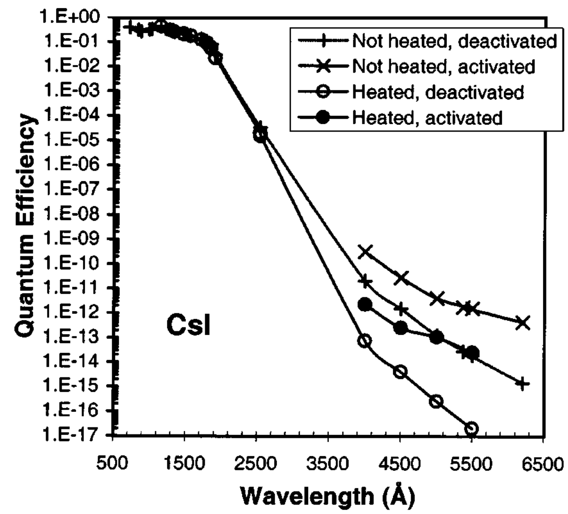

Fig. 8. Absolute quantum detection efficiency of as-deposited and heat-annealed CsI photocathode before and after activation by 1849-Å photons at illumination intensity of 1.5×10^{8} photons cm^{-2} s^{-1} and accumulated dose of 5.4×10^{10} photons cm^{-2}.

C. Improvement of Solar Blindness by Heat Annealing

We found in our measurements that heat annealing not only increases the photoconversion efficiency and stability of UV sensitivity under UV irradiation, but also improves the efficiency of visible light rejection of CsI photocathodes. Fig. 8 shows the sensitivity of the same photocathode before and after the sample was heated to ~90 °C for several hours and then cooled down to room temperature during ~6 h. The heat treatment was done in vacuum and the sample was not exposed to any air between the QE measurements. The sensitivity to 5500 Å photons is ~1000 times lower for the annealed photocathode and consequently the sensitivity of the activated annealed photocathode is also much lower.

V. Conclusion

Our study of the performance stability of CsI and KBr photocathodes under UV irradiation showed that in-band (1849 Å) illumination led to a substantially larger UV sensitivity degradation of CsI film than in the case of out-of-band 2537-Å irradiation. We conclude that out-of-band irradiation is likely to be preferable if sensitivity degradation during detector preconditioning and calibration becomes an issue. Flux rate was found to be an important parameter for the photocathode aging, with lower fluxes resulting in larger QE degradation for equal accumulated doses and irradiation wavelengths. The latter fact complicates characterization of performance stability of detection devices with alkali halide photocathodes, as very long exposure would be necessary in order to reproduce possible photocathode aging. The angle of illumination was not crucial for the UV sensitivity variation of CsI and KBr films.

As opposed to UV sensitivity variation, the angle of radiation incidence is a crucial parameter for the visible light sensitivity activation, while the flux rate was not found to be important. Heat treatment of CsI photocathodes substantially reduces their visible sensitivity and their ability to be activated to high QE values in the visible spectral range.

Acknowledgment

The authors would like to thank their colleagues from Experimental Astrophysics Group at Space Sciences Laboratory, J. M. Stock, J. V. Vallerga, P. N. Jelinsky, S. R. Jelinsky, and M. A. Gummin as well as P. Morrissey from Caltech, for very useful discussions.

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