UV Radiation Resistance and Solar Blindness of CsI and KBr photocathodes

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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 CsI photocathodes.

I. INTRODUCTION

The sensitivity of imaging and spectroscopic detectors is often increased by solid photoconverters combined with electron multipliers. Alkali halide photocathodes are currently widely used in various UV detecting devices [1]-[5] 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 the recent papers [6] - [13]. The current detailed study of the response of CsI and KBr photocathodes was performed with thin films of these materials deposited directly on the input surface of microchannel plates, 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 ≤20 Å sec⁻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 1x10⁻⁶ Torr.

The detector used in the present study consisted of a Z-stack of microchannel plates of 33 mm in diameter with 12.5 µm pores on 15 µm centers (80:1 L/D) 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 10⁷.

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 (UDT Sensors, Inc.[14]) photodiodes. A 150 Watt 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 Research Corporation (1878 and 2545 Å filters with peak transmissions of 17% and 12.5 % and bandwidths of 219 Å and 110 Å, respectively).

A 90% transmissive nickel mesh was installed ~5 mm in front of the MCP, 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 mesh bias to positive, as related to the MCP, eliminated the web photoelectron contribution to the photon counting.

Fig. 1. Opaque photocathode deposited on a microchannel plate (not to scale). Photocathode inside microchannel pores irradiated at grazing angles, while interchannel web area film irradiated at normal incidence.

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 [7],[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 ageing 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 and found that UV sensitivity of positively biased CsI photocathodes does not decay as fast as in case of negatively biased films [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 185nm photons with flux rates differing by a factor of ~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 ageing during UV exposures: for a fixed dose slower irradiation leads to a substantially larger sensitivity degradation.

The exact mechanism of photocathode ageing is not known at the present time. One of possible explanations can be formation of additional traps for photoelectrons (e.g. color centers). If coloration of UV irradiated photocathodes can explain the UV ageing 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. Ageing at Different Wavelengths

Two different spectral lines from mercury vapor penray lamp were used in our ageing studies: 1849 Å (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 non-linear 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). More detailed study of ageing as a function of dose is required in order to confirm that hypothesis.

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

Fig.4 represents the ratio of photoelectrons originated at pore photocathode to photoelectrons from the web area. In the UV spectral range that ratio is equal to the same constant before and after the photocathode ageing. 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 ageing processes, at least in 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 [3],[17] and we have observed that the visible QE increase can be as much as 4 and 7 orders of magnitude for CsI and KBr, respectively [13]. Fig.5. 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.

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 x10^{13} and 7.2x10^{13} photons cm^{-2}, flux rate 1.5x10^8 photons cm^{-2} sec^{-1}; circles – dose 6.7x10^{13} accumulated at flux rate of 2.7x10^{11} photons cm^{-2} sec^{-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 2.7x10^{11} photons cm^{-2} sec^{-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} sec^{-1}). After UV exposure the value of the ratio remains constant within UV range (area I), while 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.
Fig. 5. The quantum detection efficiency as a function of wavelength for as-deposited and UV-irradiated (activated) CsI and KBr opaque photocathodes. UV irradiation with the total dose of 5x10^{13} and 10^{14} photons cm^{-2} at 1849 Å for CsI and KBr, respectively (corresponding flux rates of 10^{8} and 10^{9} photons sec^{-1} cm^{-2}).

A. Activation versus irradiation flux rate

Similar to the ageing measurements described above, the activation of KBr photocathode was measured after equal doses of irradiation, while the illumination intensity was changed between different activation exposures. 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 ~6mm wide spot. The height of the peaks in Fig. 6 shows the level of photocathode activation.

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 exposures (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 cut off. 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 photocathode with out-of-band (2537 Å) UV illumination was almost negligible.

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 heat annealing. 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.
degradation of CsI film than in the case of out-of-band 254 nm) illumination led to a substantially larger UV sensitivity photocathode ageing, with lower fluxes resulting in larger QE flux rate was found to be an important parameter for the likely to be preferable if sensitivity degradation during wavelength. The latter fact complicates characterization of degradation for equal accumulated doses and irradiation 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 1.5x10^10 photons cm^-2 sec^-1 and accumulated dose of 5.4x10^15 photons cm^-2.

V. CONCLUSIONS

Our study of the performance stability of CsI and KBr photocathodes under UV irradiation showed that in-band (185 nm) illumination led to a substantially larger UV sensitivity degradation of CsI film than in the case of out-of-band 254 nm 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 ageing, 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 exposures would be necessary in order to reproduce possible photocathode ageing. 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.

VI. ACKNOWLEDGMENTS

Many grateful thanks are extended to our colleagues from Experimental Astrophysics Group at Space Sciences Laboratory J.M. Stock, J.V. Vallerga, P.N. Jelinsky, S.R. Jelinsky, M.A. Gummin and P. Morrissey from Caltech for very useful discussions. This study was supported by NASA grant #NAG5-3913.

VII. REFERENCES