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The stability of quantum efficiency and visible light rejection of alkali halide photocathodes

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ABSTRACT

We have studied the UV sensitivity degradation of CsI and KBr thin films under UV illumination and the stability of their visible light rejection for CsI and KBr opaque photocathodes evaporated on microchannel plates. For both materials the greatest degradation of the relative quantum detection efficiency (QDE) was observed near the photocathode sensitivity cut off, while there was almost no change in their EUV response. The ageing of the photocathodes is likely to be independent of the angle of radiation incidence. Of the two materials the CsI films appeared to be more solar blind and less subject to visible sensitivity activation by UV exposure. The QDE of KBr-coated MCP at 5500 Å increased by more than 7 orders of magnitude, from $9x10^{-15}$ to $4x10^{-7}$, after exposure to ~10^{15} photons cm^{-2} at 1849 Å, while in case of CsI photocathode the activation was only 4 orders of magnitude, from $2x10^{-17}$ to $3x10^{-13}$. The observed activation was stable in vacuum of 10^{-6} Torr over a period of at least 15 hours. Initial restoration of solar blindness by illumination with visible light is a very fast process, although the complete deactivation may require large doses. The photocathode activation in the interchannel web area was observed to be much more pronounced than that inside a microchannel pore, suggesting that the angle of radiation incidence is a crucial parameter for the activation dynamics.

Keywords: Alkali Halide Photocathodes, Quantum Efficiency, UV ageing, Visible Light Rejection

1. INTRODUCTION

It has now become a common practice to combine solid photoconverters with electron multipliers in order to increase the sensitivity of imaging and spectroscopic ultraviolet detectors. A large number of different photocathode materials have been studied and described in literature. In general, the photoconversion efficiency is the most crucial parameter determining a particular choice of a photocathode material. At the same time, the stability of photocathode response is essential for many applications, and therefore it has been the subject of a number of studies in recent years[1-7]. Alkali halide photocathodes have proved to be efficient in UV and soft X-ray ranges, and they also feature a relatively high stability when exposed to ambient air and a long lifetime when stored in a moisture-free environment. These features have made them widely used in various photon-counting devices[1,8,9], including many space born instruments[10-15]. On the other hand, it was reported that photocathode ageing under a photon flux may result in a substantial decrease of their efficiency[1,6,7]. The latter phenomenon may present one of the major problems in detector applications involving long operation time or large photon fluxes. It was already shown that post-evaporation heat treatment of photocathodes enhances their UV[1,3,7,11] and soft X-ray[16] sensitivity and also reduces the rate of sensitivity degradation after exposure to a relatively high flux UV illumination[7]. In this paper we study sensitivity degradation under UV illumination for opaque CsI and KBr photocathodes deposited on microchannel plates (MCPs) (as opposed to the flat substrate samples in our previous study[7]). The main motivation for extension of our previous studies of flat substrate ageing with CsI and KBr deposited on MCPs was to verify the significance of the angle of the incident UV flux for sensitivity degradation. In case of alkali halide layer on microchannel plates we can measure degradation of the photocathode sensitivity both inside the pores (which are illuminated at a grazing angle) and on the interchannel web area (illuminated at a normal incidence). In case of grazing incidence the UV photons are absorbed much closer to the photocathode surface and therefore the damage of the pore area may differ considerably from the damage of the interchannel web coating. Variation of the potential on the mesh positioned in front of the MCP allows us to separately measure the quantum efficiency values of the pore and web areas.

In the present measurements most of the photoelectrons were detected by an MCP (photon counting mode), while in our previous studies the electrometer sensitivity and its electronic noise required production of ~10^4 photoelectrons sec^{-1}. The limited brightness of our illumination source did not allow us to investigate the out-of-band stability of photocathodes previously. In the present experiments we were able to extend the ageing studies to much longer wavelengths and investigate in detail the stability of visible light rejection of the CsI and KBr photocathodes. In a number of applications the UV signal under study is much fainter than the signal in the visible spectral range (in some cases the studied objects can be up to 10^9 times brighter in the visible than in the UV band), so that UV imaging detectors become very inefficient in the optical range (i.e. “solar-“ or “visible-blind”). Therefore, while the efficiency of the UV detection is an important parameter determining data accumulation rate, the solar blindness of the instrument determines the possibility of studying certain objects. Although there exist a number of different techniques, which allow reduction of the out-of-band incident flux, the total rejection is not feasible and in many cases these visible rejection methods reduce the UV flux as well. Consequently in certain applications scattered visible light greatly reduces the ability of an instrument to detect faint UV signals. The previous study of the visible light sensitivity of KBr photocathode[13] showed that illuminating for several hours with a mercury vapor lamp (with the brightest line of 2537 Å and a flux of 10^{11} photons cm^{-2} sec^{-1}) may substantially increase the photocathode sensitivity to visible light with no change in the inband sensitivity. The latter activation phenomenon was observed during the preconditioning (UV scrubbing for detector gain stabilization) of MCP stack for SOHO flight detector[13]. Coluzza *et. al.*[17] observed the activation of secondary electron photoemission from CsI films after they were exposed for several seconds to 1486.7 eV X-rays with a flux of about 5×10^{11} photons cm^{-2} sec^{-1}. They also showed that the observed activation effect is related to a change in the surface morphology. In Section 4 we present a detailed study of the visible sensitivity activation by UV illumination of CsI and KBr photocathodes deposited on microchannel plates.

2. EXPERIMENTAL SETUP

We studied the CsI and KBr QE stability and activation with a detector consisting of a Z-stack of microchannel plates. The microchannel plate stack consisted of three 80:1 L/D, 12.5 μm pores on 15 μm centers, 33 mm in diameter MCPs from Photonis-SAS (for KBr) and from Galileo (for CsI) with resistances 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. A typical pulse height FWHM was about 80%.

The CsI and KBr photocathodes were vacuum deposited on 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%) photocathode material was evaporated at a rate of ≤20 Å sec^{-1} in a vacuum system at 10^{-6} Torr. Prior to deposition, the material was heated behind a shutter for several hours to outgas any absorbed water. During evaporation the MCPs were rotated at 0.5 rev/sec. All coatings were ~9000 Å thick. After deposition, the chamber was purged with dry nitrogen and then the photocathode-coated MCPs were exposed to air (with a relative humidity of <50%) for several minutes during the transfer and installation into the calibration chamber. The detector was then mounted on a manipulator with a rotation stage, which allowed rotation of ±60 degrees with ~1 degree accuracy. All the reported measurements were performed at a normal incidence to the MCP and at pressures of about 1×10^{-6} Torr.

A 90% transmissive nickel mesh was installed ~5 mm in front of the MCP. Negative biasing of the mesh relative to the MCP input provides the electric field to repel the photoelectrons emitted from the interchannel web area, into the MCP pores, thus increasing the detection efficiency. Changing the mesh bias to positive, as related to the MCP, eliminates the web photoelectron contribution to the photon counting. Therefore we were able to separately investigate the photocathode QE stability inside the MCP pores and on the interchannel web area.

The absolute UV quantum efficiency was determined from the ratio of the observed photon counting rate with the detector to the flux measured by NIST-calibrated standard EUV and FUV photodiodes. Monochromatic radiation (256-2000 Å) was provided by a gas discharge hollow cathode source in combination with a 1 m grazing incidence monochromator. A PIN UV-100 silicon photodiode from UDT Sensors, Inc.[18] was used for the visible light flux calibration. A 150 Watt white light source with a lightguide 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).

3.QE STABILITY UNDER UV EXPOSURE

Our previous studies of CsI, KBr and KI reflective photocathodes evaporated on flat stainless steel substrates showed that their UV sensitivity exhibited some degradation after the samples were exposed to ~10^{16} photons cm^{-2} from a penray lamp. The QE decrease was the most pronounced at about 1700 Å, with almost no degradation at wavelengths shorter than 1200 Å. At the same time the sensitivity of photocathodes at 1900-2000 Å increased in some cases after the samples were UV illuminated. We attributed the latter QE increase to a photocathode "activation", which at the time could not be investigated in detail due to the fact that the photocurrent from the samples at wavelengths longer than 2000 Å was below the noise level of our electrometer. A bare penray lamp inside the vacuum chamber was used for illumination, and all its spectral line contributed to the incident "damaging" flux. In the present experiments the ageing of the photocathodes was studied separately for UV exposure at two different wavelengths: 1849 and 2537 Å spectral lines of the mercury vapor penray lamp. The quantum efficiency values for CsI and KBr differ by several orders of magnitude at those two wavelengths, while the photon energy values are 6.7 and 4.89 eV, respectively. Thus the UV radiation damage to CsI photoconverter was evaluated for in-band and out-of-band illumination. The radiation fluxes during the UV illumination were periodically monitored with a NIST-calibrated FUV diode. Both the MCP and the repelling mesh were not biased during the scrubbing process to prevent any scrubbing of the microchannel plates, which otherwise might have contributed to QDE degradation through the detector gain loss.

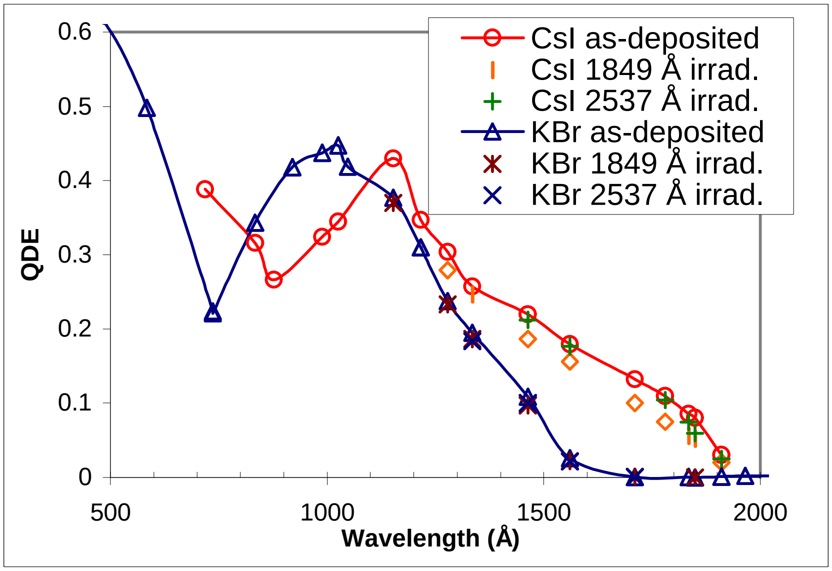

Fig.1. The absolute quantum detection efficiency as a function of wavelength for fresh and UV irradiated CsI and KBr photocathodes evaporated on microchannel plates measured at a normal incidence. CsI irradiation: the total dose of 5x10^{13} and 7x10^{16} photons cm^{-2} at 1849 and 2537 Å, respectively (corresponding flux rates of 10^{8} and 2.7x10^{11} photons sec^{-1} cm^{-2}). KBr irradiation: the total dose of 10^{14} and 10^{16} photons cm^{-2} at 1849 and 2537 Å, respectively (corresponding flux rates of 10^{10} and 2.7x10^{11} photons sec^{-1} cm^{-2}).

Fig.1 shows the quantum detection efficiencies measured before and after UV illumination for KBr and CsI opaque photocathodes deposited on microchannel plates, while the relative efficiency variation after 1849 Å scrubbing is presented in Fig.2. The 2537 Å illumination did not result in any damage for both CsI and KBr films, while after 1849 Å illumination some degradation was observed for both materials. The latter fact indicates that the damage process is not solely a function of the photon energy, and that the damage to a photocathode is more likely to occur when the photon energies are above the sensitivity threshold.

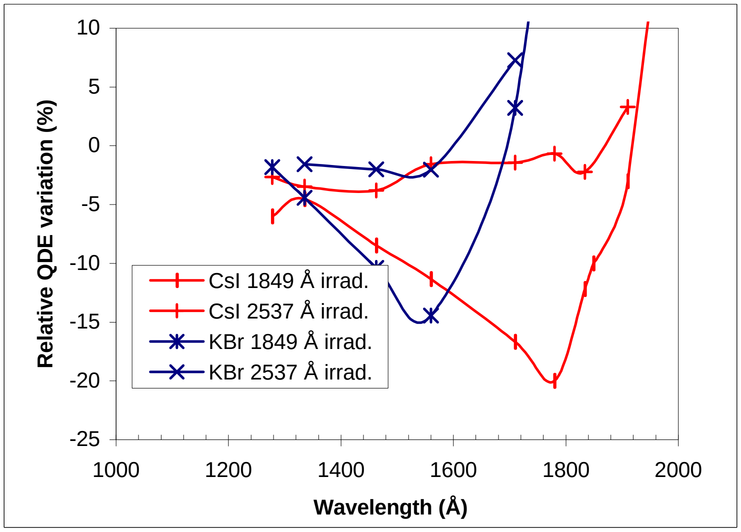

Fig.2. Relative variation of the UV quantum detection efficiency of CsI and KBr photocathodes induced by UV irradiation, normalized to initial QDE values. The illumination doses and flux rates are the same as in Fig.1.

The QE degradation of the KBr photocathode was less pronounced than that of CsI despite a larger dose of radiation, which is in agreement with our reflective film studies[7]. The observed stability of the KBr photocathode, may also be attributed to the fact, that both 1849 and 2537 Å photons have energies below the KBr cut off. The QE degradation was more pronounced at 1700-1800 Å for CsI and at 1600 Å for KBr films, where these materials have the cut off in their sensitivity. There was no variation of the photocathode response at wavelengths shorter than 1200 Å. The observed relative increase of the sensitivity at long wavelengths is described in detail in Section 4.

3.1. Angular dependence of photocathode sensitivity degradation

The dependence of the sensitivity degradation on the angle of radiation incidence was indirectly studied by observing the QE variation of the photocathode deposited inside the pores (which was subject to a grazing angle illumination) and the photocathode on the interchannel web area (which was illuminated at a normal incidence). By controlling the repelling mesh voltage we were able to either exclude or include the contribution of the web photoelectrons to the detection process and thus measure separately the QDE of "pore" and "web" photocathodes. The ratio of the web and pore photoelectron contribution to the total quantum detection efficiency was measured before and after the photocathode scrubbing (the results of these measurements are summarized in Fig.3). There was no detectable change in web/pore photoelectrons ratio and the web contribution remained at the same level of about 35% before and after UV irradiation. This fact indicates that the photocathode degraded equally in both areas despite the difference in the illumination angle. At the same time, the web contribution to the total detection efficiency does not depend on the radiation energy and is likely to be determined by the MCP geometry and the electric field at the MCP input.

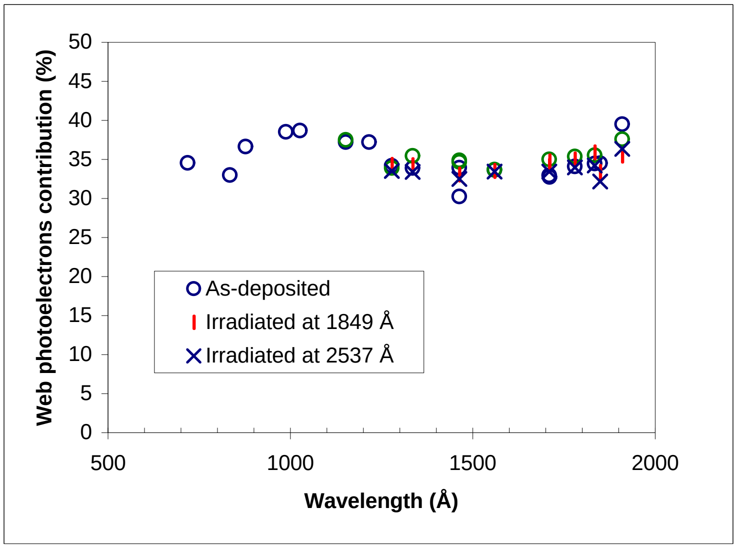

Fig.3. The contribution of the interchannel web photoelectrons to the total QDE of fresh and UV- irradiated CsI photocathode evaporated on MCP measured at normal incidence. The illumination doses and flux rates are the same as in Fig.1. The value of the web contribution remains constant with irradiation indicating that ageing of pore and web photocathodes is equal.

4.VISIBLE LIGHT REJECTION

4.1. Activation of visible light sensitivity by UV illumination

The sensitivity of alkali halide photoconverters in the visible range is extremely low, which makes them very effective in terms of solar blindness. In some applications, however, where the UV signal to be detected is several orders of magnitude weaker than the visible background, the stability of visible light rejection becomes a critical parameter.

Owing to the photon counting capabilities of an MCP detector, in the present study we managed to evaluate the stability of the photocathode response in a much wider spectral range (including visible light) than in our previous experiments with flat reflective photocathodes[7]. The intensity of light source multiplied by the photoconversion efficiency determines the number of photoelectrons produced in the detector. The sensitivity limit in the current experiments required production of as few as several photoelectrons per second and therefore the visible response of the photocathodes did not require any specific extremely bright light sources. Fig.4 and Fig.5 summarize the results of the quantum detection efficiency measurements in the spectral range of 500-6200 Å. A fresh CsI photocathode is more solar blind than KBr. Moreover, the activation by UV exposure of CsI is not as pronounced as that of KBr opaque photocathode evaporated on a microchannel plate. It was reported in the previous paper[13], where the KBr activation was first detected, that there is presumably some limit to the sensitivity increase. We observed that the level of CsI activation exhibits saturation, and the photocathode sensitivity can not be substantially increased by any further UV exposure beyond that level, or at least the rate of activation becomes very slow. The largest increase of KBr sensitivity, observed at 5500 Å in our measurements, was of more than 7 orders of magnitude (from 9×10^{-15} to 4×10^{-7}), while the CsI sensitivity at the same wavelength changed only by 4 orders of magnitude (from 2×10^{-17} to 3×10^{-13}). We found that the activation rate for the CsI photocathode was also much slower than that of KBr, although in the present experimental setup it was very difficult to investigate the activation rate quantitatively.

Some surface modifications in CsI X-ray irradiated films were detected in experiments described in Ref. [17], where the subsequent activation of secondary electron photoemission from CsI films was observed. As suggested in that paper, the visible sensitivity activation may probably also be explained by formation on the surface of irradiated photocathodes of some Cs compounds with a lower work function. The observed photodissociation of alkali halide films and formation of alkali metal islands on the surface may be considered as a confirmation of that hypothesis[18,20,21].

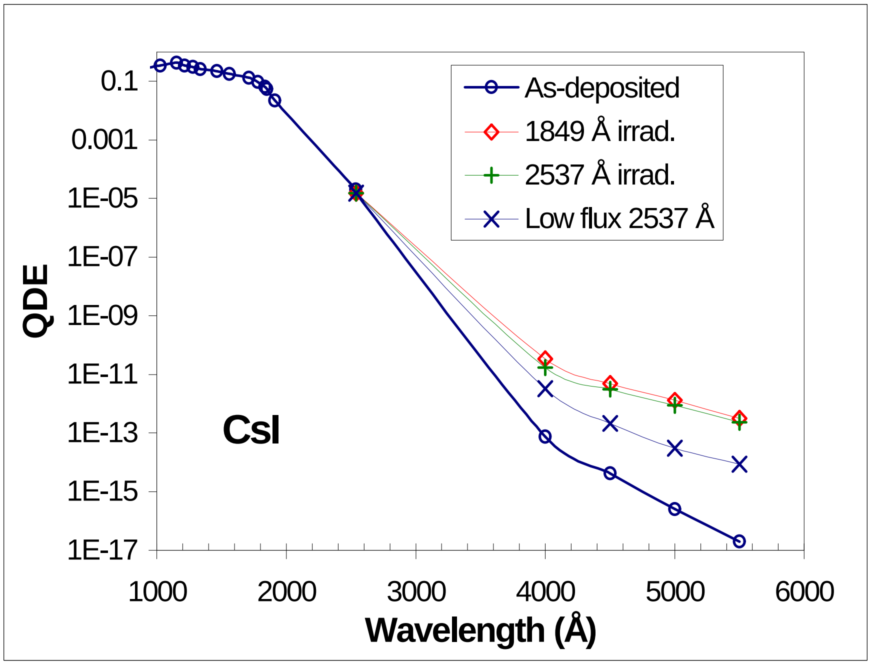

Fig.4. The visible quantum detection efficiency as a function of wavelength for as-deposited and "activated" (UV-irradiated) CsI photocathode evaporated on microchannel plate. The illumination doses and flux rates are the same as in Fig.1, plus lower flux 2537 Å irradiation with total dose of 5x10^{13} photons cm^{-2} accumulated at a flux rate of 2x10^{8} photons sec^{-1} cm^{-2}.

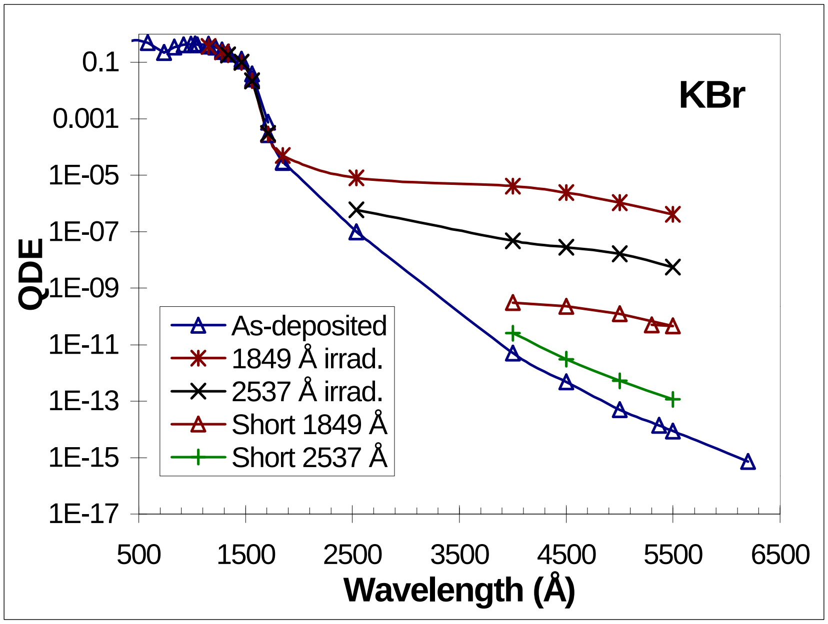

Fig.5. The visible quantum detection efficiency as a function of wavelength for fresh and "activated" (UV irradiated) KBr photocathode evaporated on a microchannel plate. The illumination doses and flux rates are the same as in Fig.1, plus lower dose and flux 1849 and 2537 Å irradiations with a total dose of 1.4x10^{10} photons cm^{-2} accumulated at a flux rate of 8x10^{7} photons sec^{-1} cm^{-2}.

4.2. Angular dependence of activation

Our measurements revealed that activation of the interchannel web photocathode (which was UV-irradiated at a normal incidence) is considerably more pronounced as compared to activation of the photocathode inside the pores, which was UV irradiated at grazing incidence angles.

Fig.6 presents the contribution of the web photoelectrons to the total detection efficiency for fresh and activated CsI and KBr photocathodes. Before activation, the CsI film did not provide any detectable photoelectrons from the MCP interchannel web area while illuminated by a visible light. In case of KBr the web contribution was also low and did not exceed the 40% level. At the same time, for both CsI and KBr photocathodes most of the photoelectrons induced by the visible light from the activated films originated at the web area. The latter fact implicitly indicates that the radiation incidence angle is a crucial parameter for the processes taking place during activation.

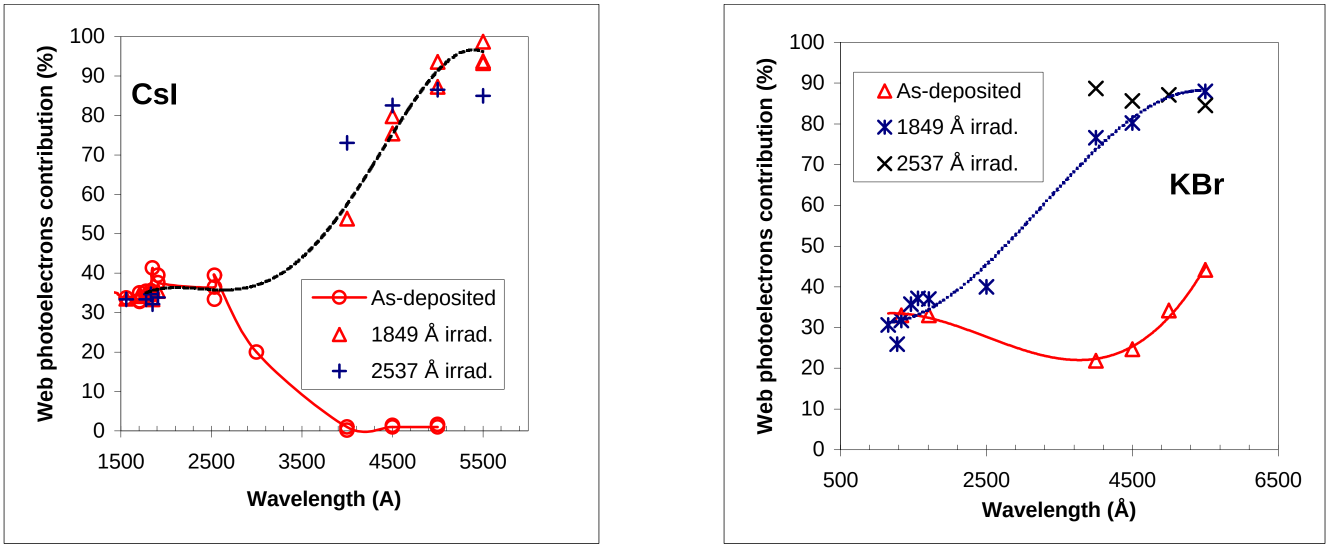

Fig.6. The contribution of the interchannel web photoelectrons to the total QDE of fresh and UV irradiated CsI and KBr photocathodes evaporated on MCP measured at normal incidence. The value of the web contribution in visible range increases dramatically for activated photocathodes. The illumination doses and flux rates are the same as in Fig.1

4.3. Activation stability and deactivation

It was reported by Coluzza *et. al.*[17] that the observed activation of secondary electron photoemission from CsI films by 1486.7 eV X-rays lasted in vacuum for about 2 days. In the present study we evaluated the stability of the visible light sensitivity activation of CsI and KBr photocathodes and estimated the rate of their deactivation. It was already reported that KBr films could be deactivated by visible light exposure. To illustrate that, we activated only a part of the detector active area coated with a KBr photocathode (approximately 1 cm^2 spot) with 1849 Å photons and then used a 530 nm laser beam to deactivate the center of that spot over a period of ~3 minutes. For the consistency of measurements the non-activated area was later also illuminated by the laser (the laser intensity was ~4x10^{15} photons sec^{1} cm^{-2}). After illumination an image of the detector response to 4500 Å photons was obtained (it is presented in Fig.7). It is clearly seen that the center of the activated spot is completely deactivated by the green laser. Similar results were obtained with a red laser (~620 nm) deactivation.

A brief exposure (for about 10 minutes) of CsI photocathode to air of about 40% humidity did not result in a complete deactivation. The subsequent white light exposure further reduced the visible sensitivity of the detector, indicating that the presumed surface modifications of the cathode are quasi-stable when exposed to air.

The activation of the photocathodes also appeared to be stable over a period of at least ~15 hours. The visible sensitivity did not decay when the detectors were held in vacuum of 10^{-6} Torr. On the contrary, the sensitivity of the films was partially deactivated by white light exposure and even exhibited some recovery with time, Fig.8. The latter fact suggests that the dynamics of deactivation include some recombination and/or diffusion phenomena.

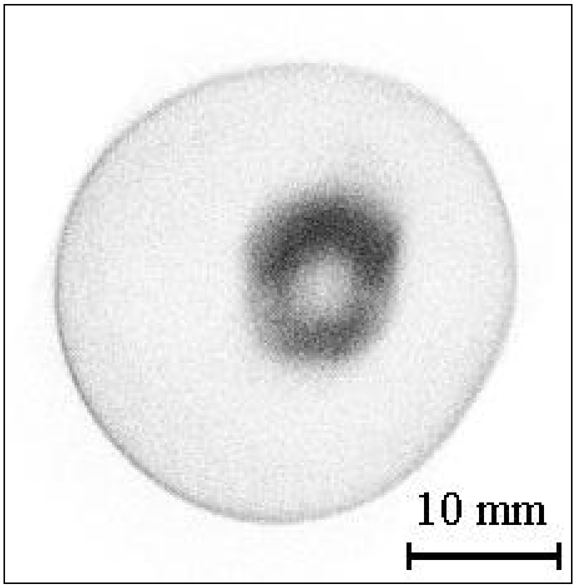

Fig.7. A full field illumination image of locally activated-deactivated KBr photocathode obtained with 4500 Å illumination. The dark area on the image corresponds to a higher detector visible sensitivity induced by the photocathode activation (approximately 1 cm^2 area). The middle of the activated area was subsequently irradiated with a green laser to illustrate deactivation by visible light exposure.

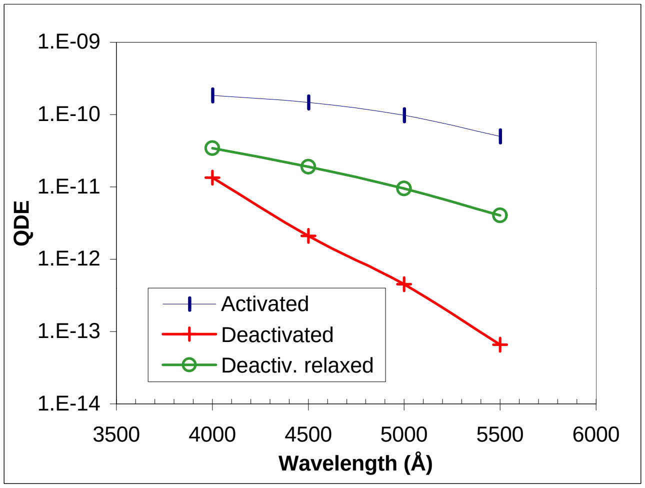

Fig.8. Temporal partial recovery of visible sensitivity activation of KBr photocathode evaporated on MCP. Diamonds – the absolute quantum detection efficiency of photocathode activated with ~$3x10^{11}$ 1849 Å photons cm^{-2} at a flux rate of ~10^{10} photons sec^{-1} cm^{-2}. Crosses – QDE measured immediately after the photocathode was deactivated by a white light. Circles – QDE measured 17 hours after the deactivation process took place. The visible activation has partially recovered.

The rate of KBr sensitivity deactivation by the visible light exposure is presented in Fig.9. We used both an unfiltered white light and the green part of the spectrum (around 5500 Å) of the same light source. First, the activated KBr film was deactivated by the entire spectrum of the white lamp and the photocathode sensitivity to 5000 Å photons was periodically monitored (the circles in Fig.9). Then the photocathode was left in vacuum for 16 hours without any illumination and the further deactivation was performed by the green part of the white lamp spectrum (the triangles in Fig.9) with a photon flux of $\sim 10^{16}$ photons sec^{-1} cm^{-2}. The visible sensitivity of the photocathode partially recovered over this 17-hour interruption of the restoration process. The analysis of the deactivation dynamics shows that the visible sensitivity is drastically reduced during the first minutes of illumination, while a complete restoration of solar blindness might still require a prolonged exposure.

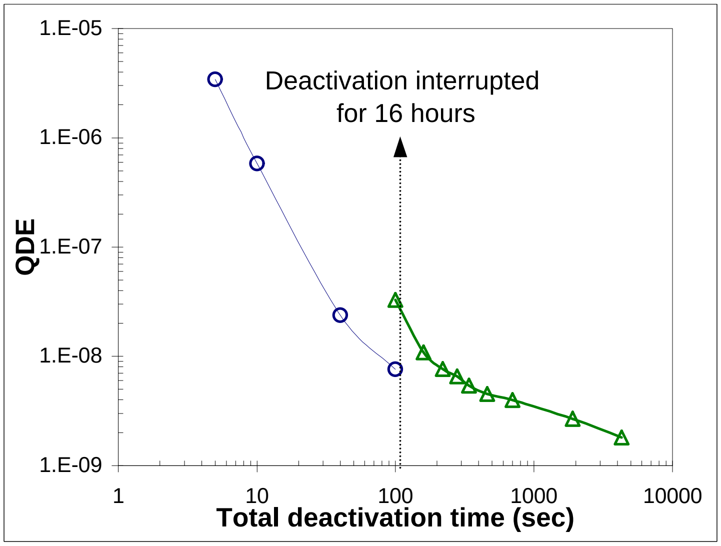

Fig.9. The rate of visible sensitivity deactivation of the KBr photocathode by a visible light exposure. Absolute QDE at 5000 Å measured as a function of deactivation time. Circles – white light exposure (150 Watts light source with a lightguide). Triangles – deactivation with the green part of the spectra (~5500 Å) from the same light source (measured "green" flux rate of about 10^{16} photons sec^{-1} cm^{-2}). Deactivation was interrupted after 100 sec of white light illumination for about 16 hours. A partial recovery of sensitivity was observed over that period.

5.CONCLUSIONS

The present study of the QE stability of CsI and KBr photocathodes evaporated on microchannel plates confirmed that UV sensitivity degradation might be a concern for some applications where high incident UV fluxes are involved. In accordance with our previous measurements with the reflective planar photocathodes, the largest relative QE degradation under UV irradiation was observed near the sensitivity cut off for both CsI and KBr films (1800 and 1600 Å, respectively). The ageing of the photocathodes is likely to be independent of the radiation incidence angle, since degradation of sensitivity was similar for both the pore and web area photocathodes illuminated at grazing and normal angles, respectively, although a direct and more detailed study of the angular dependence would be desirable.

The visible light rejection of CsI photocathodes appeared to be much better than that of KBr films, making CsI preferable for applications with extremely weak UV fluxes where scattered visible light might dominate in the detector signal. Not only is the visible sensitivity of KBr photocathodes higher, but it also can be substantially increased by UV irradiation. The activation of photocathodes is stable over a period of at least 15 hours and it can be completely revoked by visible light exposure. The recovery of the photocathode visible light rejection takes place mostly during the first minutes, however a complete deactivation may require long exposure or extremely bright light sources. We observed that activation of a photocathode deposited in the interchannel web area is much more pronounced than activation of a pore photocathode. The difference in the activation rate is likely to be explained by the differences in the angles of activating incident radiation. The wavelength dependence of the UV sensitivity degradation and visible activation are the subject of our ongoing measurements. We also plan to evaluate whether the QE variation for illumination with a given wavelength is determined solely by the total accumulated radiation dose, and/or the UV illumination flux rate.

6. ACKNOWLEDGEMENTS

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