Coated photocathodes for visible photon imaging with gaseous photomultipliers

E. Shefer*, A. Breskin, R. Chechik, A. Buzulutskov1, B.K. Singh, M. Prager2

Department of Particle Physics, The Weizmann Institute of Science, 76100 Rehovot, Israel

Abstract

We report on our latest results of K-Cs-Sb visible photocathodes, coated with thin CsI and CsBr protective films, for applications within gas avalanche photomultipliers. Data on the sensitivity to exposure to oxygen and moisture is presented, as well as on the stability under gas multiplication and aging under gas avalanche. There are good indications that the protected photocathodes can withstand long-term multiplication mode, with low-level impurity gases. Possible applications are discussed. © 1999 Elsevier Science B.V. All rights reserved.

1. Introduction

Large-area photodetectors for UV photons, based on the coupling of a CsI solid photocathode to a gaseous electron multiplier, have become a reality and are currently being built or projected for Cherenkov ring imaging (RICH) in numerous particle physics experiments ([1,2]; for numerous contributions on CSI-based Photodetectors, see Ref. [3]). Aiming at extending the spectral range of such detectors towards visible light, we have carried out an extensive study of the protection of alkali-antimonide photocathodes from impurities common in gases such as oxygen and moisture [4–7]. The protection of the photocathodes is achieved, though at the expense of some reduction in the quantum efficiency, by coating them with a thin dielectric film. It allows for the transport of photoelectrons from the photocathode through the film to the gas, while preventing contact between the gas impurities and the photocathode. Earlier works by Peskov et al. [8,9], coating Cs–Sb photocathodes with CsI films, resulted in a very low quantum efficiency of 0.15% at wavelength 350 nm.

We have previously reported on our two best composite photocathodes: K–Cs–Sb coated with thickness of 300 Å CsBr or 250 Å CsI [6,7], and on their production technique [10]. These photocathodes show quantum efficiency superior to 3% at 220–350 and 185–330 nm respectively, with a maximum of 5% at 300 nm. They can withstand long exposure to considerable doses of oxygen. For example, a 250 Å CsI-coated K–Cs–Sb photocathode can withstand an exposure of over an hour to 150 Torr of oxygen without any noticeable losses in quantum efficiency [7]. We also demonstrated

*Corresponding author.
E-mail address: fnefrat@wis.weizmann.ac.il (E. Shefer)
1 Currently at BINP Novosibirsk, Russia.
2 ELAM Ltd., Jerusalem, Israel.
that charging-up and aging by large flux of photons should not limit the practical use of these photocathodes [7].

We will report here on our further investigations of these photocathodes: the dependence of the protection capability on the film thickness, exposure to water vapor, gas multiplication in a parallel-plate mode and preliminary investigations of photocathode aging by avalanche ions. Possible applications will be briefly discussed.

2. Results and discussion

The coating film thickness is a compromise between the need for efficient electron transmission (high quantum efficiency), and the need for high stability when exposed to gas impurities. Fig. 1 shows the results of exposing bare and CsI-coated K–Cs–Sb photocathodes to oxygen. Each data point represents an exposure of a photocathode, for 5 min, to oxygen at a known pressure, followed by quantum efficiency measurement at 312 nm, in vacuum. The bare photocathode, with an initial quantum efficiency of 30%, cannot withstand an exposure to even $10^{-5}$ Torr of oxygen. Coating the photocathode with a 200 Å thick CsI film, results in a quantum efficiency of 10% and stability for up to 0.1 Torr of oxygen. A 250 Å thick CsI film coating results in a 4–5% quantum efficiency and a stability at 150 Torr of oxygen up to an hour and a half [7]. The optimal film thickness therefore depends on the specific application for which the photocathode is required, on the gas purity (usually a ppm level) and on the foreseen post-evaporation handling.

It is known that alkali-halide and alkali-antimonide films are particularly sensitive to moisture. The results of exposing K–Cs–Sb photocathodes, coated with 300 Å thick CsBr and 250 Å thick CsI films, to water vapor are shown in Fig. 2. Each data point represents 5 min of exposure to water vapor at a given pressure, followed by quantum efficiency measurement in vacuum. The water vapor pressure was measured using a residual gas analyzer for low pressures, and a hygrometer for higher pressures. Both coated photocathodes are completely degraded when exposed to $10^{-5}$–$10^{-4}$ Torr of water vapor. The difference between the two is within the experimental error and thus insignificant. A possible explanation for this degradation is the hygroscopic nature of CsBr and CsI. This is supported by the results of a recent extensive SEM study of the surface morphology of alkali-halide films [11,12]. It shows that uniformly evaporated CsBr and CsI
films, a few tens of nm thick, form clusters after being exposed to a humid environment. Such cluster forming of the coating film exposes the underlying K–Cs–Sb photocathode to moisture, resulting in its degradation.

The stability of operation of our composite photocathodes was investigated under gas multiplication. The study was done in a 1 mm gap parallel-plate multiplying geometry, in which all ions hit the photocathode. Fig. 3 shows a gas multiplication curve measured in a parallel-plate mode, using a semitransparent K–Cs–Sb photocathode coated with a 300 Å thick CsBr film. Stable gains of $10^4$ were measured at 1 atm of methane for both CsBr- and CsI-coated K–Cs–Sb photocathodes. The exponential behavior of the gain with the applied potential, indicates the absence of secondary effects.

Aging of photocathodes by back drifting avalanche ions could be one of the major problems when coupling a photocathode to a gaseous electron multiplier. Peskov et al. reported that coated Cs–Sb photocathodes are more stable than uncoated ones, under gas avalanche conditions [8]. We measured aging of a CsI-coated K–Cs–Sb photocathode in a 1 mm gap parallel-plate geometry at 1 atm of methane. The gas multiplication factor was approximately 500 and the current density 10 pA/mm$^2$. Our preliminary results, presented in Fig. 4a, show a strong decrease in photocurrent, to 20% of the initial value over the initial accumulated charge of 0.25 μC/mm$^2$, followed by rather constant photocurrent values over a few μC/mm$^2$. Astonishingly, a similar behavior was observed when replacing the CsI-coated K–Cs–Sb photocathode by a plain stainless-steel photocathode, suggesting a possible measurement artifact. Fig. 4b shows the relative photocurrent of the CsI-coated photocathode, normalized to that of the stainless-steel one. The normalized photocurrent shows a decrease to about 85% of the initial value after an accumulated charge of 2 μC/mm$^2$, but the large error bars do not permit one to draw any accurate conclusions. This preliminary result of the aging of CsI-coated K–Cs–Sb photocathode is compatible with aging results of CsI photocathodes on stainless-steel substrates, carried out in an MWPC geometry with 1 atm of methane [13].

3. Summary

We have presented our recent results on the characteristics of CsI- and CsBr-coated K–Cs–Sb photocathodes under exposure to impurities and in combination with a gas electron multiplier. Excellent protection against oxygen was observed. We showed that by varying the coating film thickness, one could tailor the protection capability over a broad range of impurity levels. The protection is reached at the expense of a reduction in quantum efficiency. However, very reasonable values of 5% and 10% at 312 nm were reached with respective protection capabilities to 150 and 0.1 Torr of oxygen. Protection against impurities at the ppm or sub-ppm level may require thinner protection films, hence higher quantum efficiency values. Alkali-halide films failed to protect K–Cs–Sb photocathodes against moisture. Such protection may be achieved by coating the photocathodes with other films, possibly polymers [14] or with double film layers; the first protecting against oxygen and the other from humidity.

Stable operation of coated photocathodes under gas multiplication, at a gain of $10^4$, was measured in parallel-plate mode; no secondary effects or up-charging were observed. Our preliminary results of
The CsI- and CsBr-coated K–Cs–Sb photocathodes offer a spectral sensitivity over a wider energy range (cutoff at 2.8 eV) compared to TMAE or to CsI photocathodes. This could be useful when applying them to RICH, provided higher quantum efficiency can be reached. The figure of merit, \( N_0 \), for a radiator reflectivity coefficient of 1, a quartz window with transmission coefficient of 0.9 and a mirror reflectivity coefficient of 0.9 (all coefficients are energy averaged), calculated for K–Cs–Sb photocathode coated with 250 Å and 200 Å thick CsI films is 50 and 70 cm\(^{-1}\) respectively. This is a low value compared to \( N_0 = 137 \) cm\(^{-1}\) calculated for TMAE-based detectors, but of the same order as \( N_0 = 80 \) cm\(^{-1}\), calculated for CsI-based detectors (these calculations were done with data from Ref. [15]).

Other possible applications of large-area gaseous photomultipliers with film-protected photocathodes are in scintillation calorimetry, scintillating fiber trackers and large medical imaging detectors, where the sensitivity to blue light may be useful. A possible application in a different field of physics is in laser triggered intense electron sources used in RF cavities [16], where the photocathodes should withstand relatively poor vacuum conditions for long periods of time.

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References

[12] T. Boutboul et al., On the surface morphology of thin alkali-halide photocathode films, WIS-99/16/Apr.-DPP.