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Cs Based Photocathodes for Gaseous Detectors

A. Borovick-Romanov

*Institute for Physical Problems
Russia*

V. Peskov

*Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510*

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A. Borovick-Romanov,
Inst. for Phys. Problems, Russia

V. Peskov
Fermi Nat. Accel. Lab, USA

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Abstract

We demonstrated that some standard photocathodes SbCs, GaAs(Cs), Au(Cs) can easily be manufactured for use inside gaseous detectors. When filled with clean quenched gases such detectors have a quantum efficiency of a few percent in the visible region of the spectra and can operate at a gain $>10^3$.

We tried to make these photocathodes more air stable by protecting their surfaces with a thin layer of CsI or liquid TMAE. The most air stable were photocathodes with a CsI protective layer. At wavelengths ≥ 185 nm such photocathodes have the highest quantum efficiency among all known air stable photocathodes, including CsI. Gaseous detectors with such photocathodes can operate at a gain of 10^5 .

Results of first tests of doped CsI photocathode are also presented. Possible fields of application of new photocathodes are discussed.

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A. Borovick-Romanov
Ins. for Phys. Problems, Russia
and
V. Peskov
Fermi Nat. Accel. Lab, USA

1. Introduction

Recently proposed parallel-plate avalanche counters (PPAC) with a CsI photocathode [1] are the subject of intense study (see for example [2] and references therein). Detectors with solid photocathodes are very fast (time resolution $<0.5\text{ns}$ [3]) because they do not have a conversion gap, where the difference in the drift time for different primary electrons creating a jitter. Fast gaseous detectors with solid photocathodes are attractive for many applications such as RICH[4], readout of VUV scintillators[5] and noble liquids[6]. Pure CsI photocathodes are sensitive only to wavelengths shorter than 220nm, thus restricting their range of application. Historically, several attempts have been made to find suitable photocathodes, sensitive at longer wavelength and compatible with gaseous detectors (see for example[7]). As turn out that is an extremely difficult task especially if one requires exposure to air. One can conclude from this preliminary study that in order to reach high efficiency for $>220\text{nm}$, it is necessary that either the

detector be sealed or, if some air resistance is necessary, the photocathode should be covered by a protective layer and than it losses a considerable fraction of its efficiency. The first approach may work well for some applications like astrophysics where traditionally sealed detectors are preferable. The second approach is more attractive for High Energy Physics where basically large, flushed gaseous detectors are used. In the present paper we report on our current progress in both directions.

2. Photocathodes for a sealed gaseous detector

Cs photocathodes have been known for a long time[8]. They are sensitive to visible light, but are also very reactive with air. On the other hand, there exist commercially available Cs generators which allow one to evaporate Cs in vacuum in a simple way. Sealed gaseous detectors with the Cs photocathodes obtained by such a technique have been previously described in ref. [9]. The authors of work [10] succeeded in manufacturing in the laboratory a SbCs photocathode. First , a Sb film was evaporated on a substrate in vacuum. Then the Sb photocathode was installed in air inside a PPAC and covered by Cs from the Cs generator after which the chamber was filled with clean methane and sealed. The authors of this work reached remarkably high and reproducible QE in the visible region, a few % at 440nm with stable operation in a methane atmosphere.

In the present work, we reproduced the results of[10] and tried to use a Cs generator in order to produce even more simple photocathodes -GaAs(Cs) and AuCs while checking their operation in different quenching gases at high gain.

The set up we used was essentially the same as in ref. [10] and is shown on fig 1. A small PPAC with Sb, GaAS (p-type) or Au cathode was mounted inside a T shape glass tube with a quartz window. An anode electrode mesh plane was placed 2 mm away from the cathode. The Cs generator was placed 1-3 cm in front of the mesh. Before evaporation of the Cs from the generator the chamber was heated to 100°C and pumped for 96 hours. As a light source a Hg lamp with narrow band filters was used. The quantum efficiency (QE) of our photocathode was measured with respect to the known QE of TMAE and several phototubes as described in ref. [2]. We measured the current while evaporating holder the mesh at a fixed voltage of 10V. When the current passed through the maximum the evaporation was stopped. After the evaporation of Cs from the Cs generator, we measured the photocurrent from the photocathode as a function of applied voltage in vacuum, Ar, CH₄ or isobutane with and without TMAE vapors.

The results of our QE measurement of photocathodes are presented in fig.2. One can see that in CH₄ the QE of a few to 10% was achieved in the spectral interval 180-450nm. The detector can work at gain of 3-5 10³. In Ar the QE was considerably lower especially at long wavelengths. For a comparison, the same data for the SbCs photocathode's from ref.[10] are presented.

With the chamber heated and pumped 96 hours before the photocathode manufacturing some degradation of the QE in time was observed -see fig.3. We should note that with a better prepared chamber (heating to 300C during 1-2 weeks) no degradation of the QE with time was observed [9,10].

We also did some preliminary test of the aging of the SbSc and GaAS photocathodes. In this test, the photocathode was continuously irradiated by the filtered UV light (220nm) at gaseous gains of 1-10. The results obtained in CH₄ are presented in fig.4. We found that the higher pressure of the gas the less aging occurs. After blocking the light, the QE was partially restored, indicating that there is some recovery with the

light off. The same tendency was observed as in the case of CsI photocathodes [11]. In Ar, a considerable drop of the QE was observed at collected charge of $1\mu\text{ C/cm}^2$.

Results of this work together with results published in ref.[10] indicate that there is a simple and reproducible technology for producing photocathodes sensitive to the visible region of the spectrum and suitable for use in gaseous detectors

3. Photocathodes with some air resistivity

The photocathodes described above have a remarkable QE, but they are extremely sensitive to O_2 , H_2O and other impurities. As a result, they can be used only in very clean gaseous atmospheres. We tried to develop more robust photocathodes, which one can use in more practical conditions: small leaks, dirty gases . In this section we describe the results of few such attempts

3.1 Photocathodes with a protective layer

Two types of materials were tested to protect photocathodes while exposed temporarily to air. These were a TMAE or CsI layer.

a) TMAE protective layer

As was shown in previous works [7, 2], the air sensitive photocathodes can be temporarily protected by covering them with a thin layer of d,d-dimethyl-trimethyleneferrocene-phane or ethylferrocene, or TMAE. Measurements of stability with time of the SbCs and SbCs+TMAE photocathodes, taken from commercial phototubes, were

published elsewhere [2]. It has some air durability probably due to the reaction of oxygen with TMAE, which removes oxygen and works like some kind of getter.

As soon as the SbCs photocathode are easily manufactured in the laboratory while also working in the atmosphere of $\text{CH}_4 + \text{TMAE}$, showing some resistance to air, then this makes the photocathode usable even for poorly sealed gaseous detectors. Results of our tests on the stability of the SbCs photocathode, manufactured in such a way, are presented in fig.3. By comparison with the results obtained with a commercial photocathode [2], one can conclude that our photocathode is more robust (probably due to the lower initial QE). In this experiment, we also found that an optimum pressure of TMAE vapors (≤ 0.03 Torr) exists. At higher pressure, the QE degrades faster but restores practically completely after pumping the TMAE. Gaseous detectors with such photocathodes can work at gains of 10^5 . The air resistivity of the GaAs(Cs)+TMAE and AuCs +TMAE photocathodes were much worse than SbCs +TMAE.

b) CsI protective layer

In the work presented here a protective layer of thin CsI was also tested. It is known that a thin layer of CsI is transparent for photons and photoelectron and this effect is explored in semitransparent photocathodes for gaseous detectors [12].

For the manufacturing of Cs+CsI photocathodes we used the evaporation system set up similar to that described in ref. [2]-see fig.5. Inside the vacuum jar was installed a Cs generator and a boat with CsI crystals. A few Cs coated substrates were tested: Al, SbCs, GaAs, Au. In the case of an Al substrate, it was first coated by a thin layer of Cs (8-10nm) and then immediately after that by a protective CsI layer (5-50nm). Then TMAE vapors were introduced into the jar. After TMAE the jar was filled with N_2 up to 1atm and opened to air. During 1-2 min the photocathode was transferred to the test chamber, described in ref.[2]-see fig.6. The gap between the cathode and anode mesh was

1.5mm. The chamber was immediately sealed, pumped and the QE measured by means of Hg lamp and filters in vacuum or gas media.

The most reproducible results were obtained with those photocathode that remained in contact with TMAE vapors. It was found also that the QE of the photocathode with the Cs protective layer was strongly dependent on the electric field. The highest QE was achieved in vacuum at an applied voltage $>3\text{kV}$ -see fig7. In order to avoid the discharge due to the residual TMAE vapors in the chamber the photocathode plate was cooled to about 0°C . In the presence of a gas atmosphere of CH_4 or isobutane we were not able to apply so high a voltage and the QE measured was 3-5 times lower in CH_4 and 10 times lower in isobutane. In vacuum or CH_4 , the photocathode was rather stable. But in isobutane the QE dropped with time much faster, -a factor of 2 during 30-40min.

Better results were obtained with $\text{SbSc}+\text{CsI}$, $\text{GaAs}(\text{Cs})+\text{CsI}$ and $\text{Au}(\text{Cs})+\text{CsI}$ photocathodes. Substrates of these photocathodes initially are much more sensitive to visible light than Al and one can expect therefore higher QE after CsI coating. Indeed the best results were obtained with a GaAs and SbSc substrates-see fig.7. The QE of the protective CsI layer itself is small compare to the QE actually achieved [13]. One can clearly see from fig.7 that the efficiency of penetration of the photoelectrons through the protective CsI layer sharply increases at shorter wavelengths. This photocathode has also the best air resistivity and we achieved reproducible results even without exposing it to TMAE vapors in the jar after the evaporation -see fig 8. At a wavelength region $>185\text{nm}$ the QE of these photocathodes is highest among any other known air stable photocathodes including CsI. Probably at wavelength $<185\text{nm}$ the QE of our photocathodes is still higher than CsI. We checked also that the gaseous detector with such photocathode can work at a gain of 10^5 . This may open a lot of application of such photocathodes. Preliminary test show that the aging properties of the photocathodes with a CsI protective layer is at least one order of magnitude better than without. We should

note that with the thinner CsI protective layer (5-10nm) the QE was factor 2-5 higher in the visible region , but the photocathodes lost their durability to air. We tested also a simple apparatus allowing one to transfer the photocathode from the jar in to the test chamber without exposure to air. The QE we got in this case was closed to that obtained with the SbCs+TMAE photocathode -see fig. 7.

We believe that protection with the CsI layer is the most perspective way of producing air stable photocathodes sensitive to UV and blue light.

3.2 Doped CsI photocathode

Dopants in the CsI change their structure and as a consequence a new absorption band appears. A typical example can be CsI doped by TI, when the absorption band shifts from 220 to 260nm.

It has been known for a long time that doping of alkali halides with an excess of metal improves its QE in some wavelength range an order of magnitude [14], but according to our knowledge this has not been used for a practical device. In order to produce the doped CsI photocathode in the jar described above, we evaporated at the same time both CsI and Cs. Three independent thickness monitors were used to measure the thickness of Cs, CsI and Cs+CsI during the coating. Unfortunately, in this set up we were not able to precisely control, for any time, the evaporating rate of the CsI and Cs and this gave us a considerable spread in QE. Our best results are presented on fig.3. Although in some cases we were able to get rather high QE, results were not well reproducible. Additionally, we found that the QE of such photocathodes drop with time-factor 2 in 7 min. Nevertheless, the results already obtained indicate that photocathodes efficient enough in the visible region can be obtained in such a way.

4. Discussion

As a result of this work we confirmed the measurements of ref. [10] and demonstrated that photocathodes with a few % efficiency in the visible region (SbCs, GaAs, AuCs) can be made in a simple way such as evaporated inside a clean and well pumped detector. Such photocathodes operate stably in CH₄ atm at low photon flux and allow us to reach a gain of at least 10³. At high photon flux, the photocathodes suffered from "aging" and this problem should be carefully studied in the future. We feel that is not due to ion bombardment, but impurities and dissociation products are mostly responsible for the aging. Indeed in noble gases or in hydrogen [9] the aging characteristics were 10-100 times better. Probably this problem can be solved as it was done with a CsI photocathode [15]. We should mention that bialkali photocathodes were also tested in CH₄ atmosphere [16]. These photocathodes are sensitive up to 600 nm and as a result of this the maximum gaseous gain achievable was only about 100. Nevertheless all these independent works [9,10,16] demonstrated that visible photocathodes can be used in sealed gaseous detectors. For the coating of large surfaces one can use the technique where the cathode moves during the evaporating process, as was used by the group in Protvino for a similar development [17].

We should note that there exist some commercially available phototubes filled with Ar. However, in Ar it is impossible to reach high gain and good time and space resolution due to photon feedback. Our measurements also showed that in Ar long wavelengths are much more suppressed than at short wavelength. As was shown before at a gain >10³ one can reach rather good time resolution 1 ns [3] and such detectors can be position sensitive [18]. Another advantage of gas filled detectors is its insensitivity to

magnetic fields [16]. We hope that our results will encourage other investigators and photonic companies to develop detector of visible photons filled by quenched gases. Depending on their construction (for the possible design see ref. [18,19]) they can be use for the detection of scintillation light from crystals and fibers, in Cherenkov detectors and possibly in other applications,

Very encouraging results were obtained with air stable photocathode SbCs+CsI, GaAs(Cs)+CsI, with the CsI protective layers. These photocathodes have record sensitivity at wavelength >185 nm and can be used everywhere where the CsI photocathodes were used before or planned to be used(see for example review [20]) .

The physics of the penetration of photoelectronst through such a thick layer is not so clear. Other work [12] has shown experimentally that in the case of semitransparent CsI photocathodes the optimum thickness is about 10nm. Few theoretical models describing the results were reviewed elsewhere [12]. In our case thin layers of CsI did not protect the photocathodes efficiently from air. We used a 30nm coating. At thicknesses of 1-30nm both the Cs and the CsI layer are not uniform and look more like patches. One can imagine that electrons move along the surfaces between the photocathode and the protective layer and are extracted through some cleaves and cracks.

Much more modest results were obtained up to now with previous photocathodes, having some air resistivity and a sensitive to visible light. The best obtained up to now were SbCs , CsTe [7] or doped Cs covered by TMAE layer. Although the first photocathode has better QE the last one was more airstable. On the other hand SbCs photocathode can be simply evaporated inside the detector or, if necessary, transfer from the evaporating system in to the detector without exposure to air. More systematic work should be done in this direction.

Less success in the search for air stable photocathodes with a high QE in the visible the region of spectra reflects probably fundamental limitation in this direction. On the other hand, the QE already achieved can be sufficient for some particular applications

like Plasma physics where the photon flux is usually very intense [21] or air shower experiments, where the shape of the QE, presented on fig.8 (SbCs+CsI+TMAE), is close to the ideal [22].

5. Conclusion

Results of our work demonstrate that the photocathodes sensitive to the visible region, can be easily manufactured inside sealed gaseous detectors. When filled with clean quenched gases, they can operate stable at gain up to 10^3 .

TMAE vapors reduced the QE, but the photocathodes obtained some air durability and the detector can operate at gain 10^5 .

We developed air stable photocathodes with the CsI protective layer, which has the highest sensitivity for wavelength >185 nm among all air stable photocathodes including CsI.

It looks that there are fundamental limitations in attempts to find air stable photocathodes with a high QE in the visible region of the spectra (>400 nm)

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Figure captions

Fig.1.Set up for the manufacturing and testing of Cs-based photocathodes .

Fig2. Typical QE obtained in CH₄ (20Torr) with GaAs, SbCs and Cs photocathodes.

Fig. 3 Stability with time in CH₄ obtained with GaAs, SbCs and SbCs+TMAE photocathodes. For a comparison the data from ref. [10] are also shown

Fig4. Aging test of SbCs photocathodes

Fig5. Set up for the evaporation of Cs and CsI photocathodes

Fig6.PPAC for the tests of air stable photocathodes

Fig.7 The QE of different photocathodes covered by a TMAE protective layer

Fig 8. The QE of GaAs and SbCs photocathodes covered by a CsI protective layer

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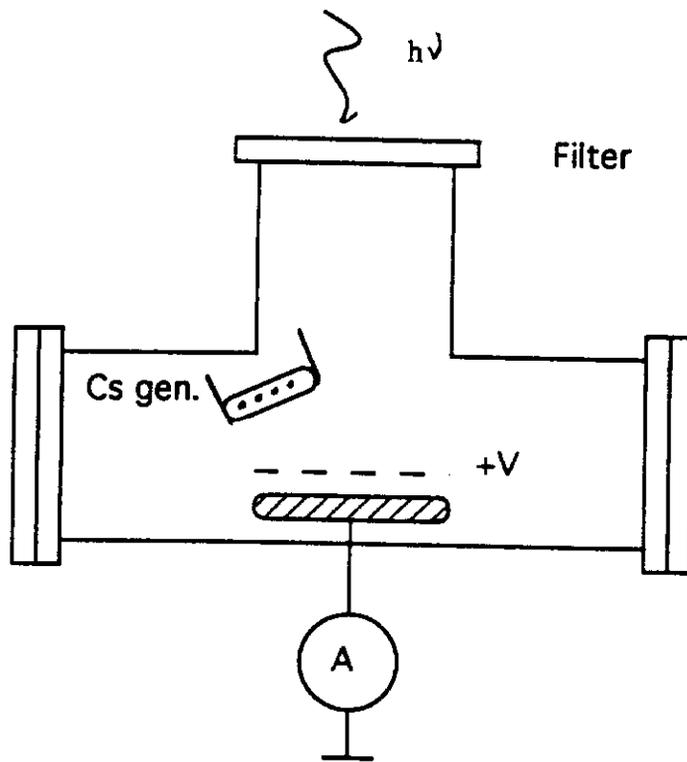


Fig. 1

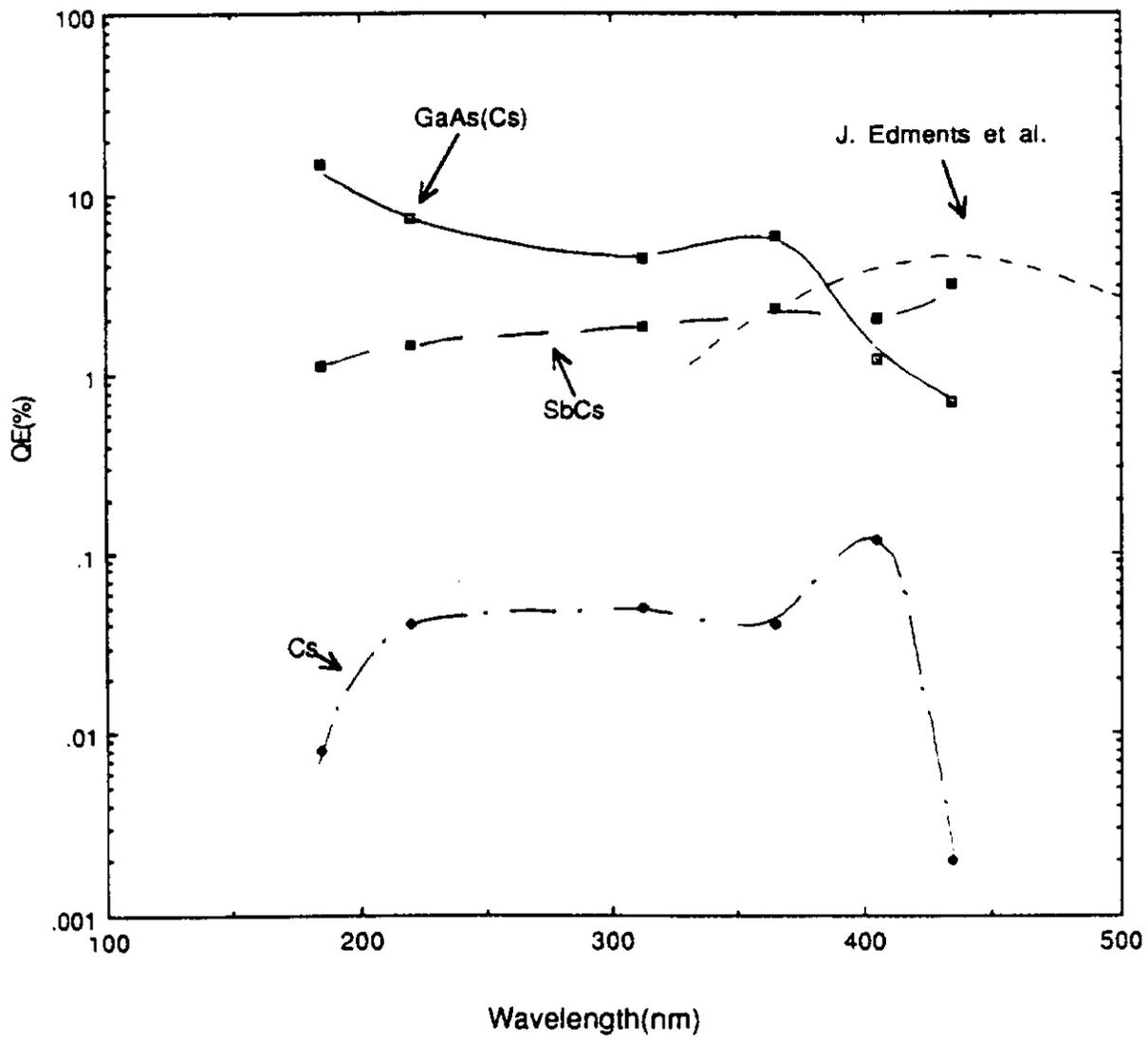


Fig. 2

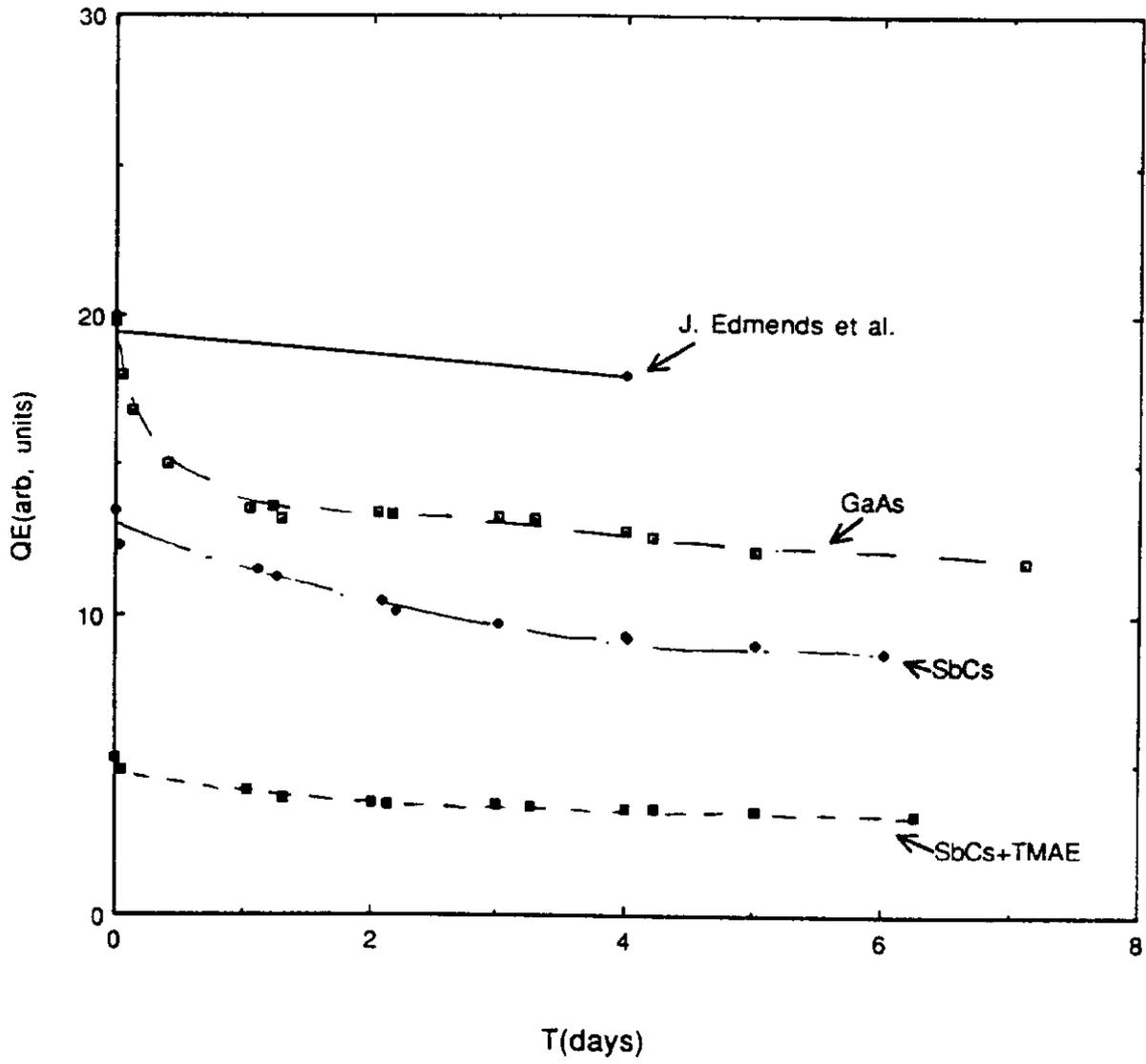


Fig. 3

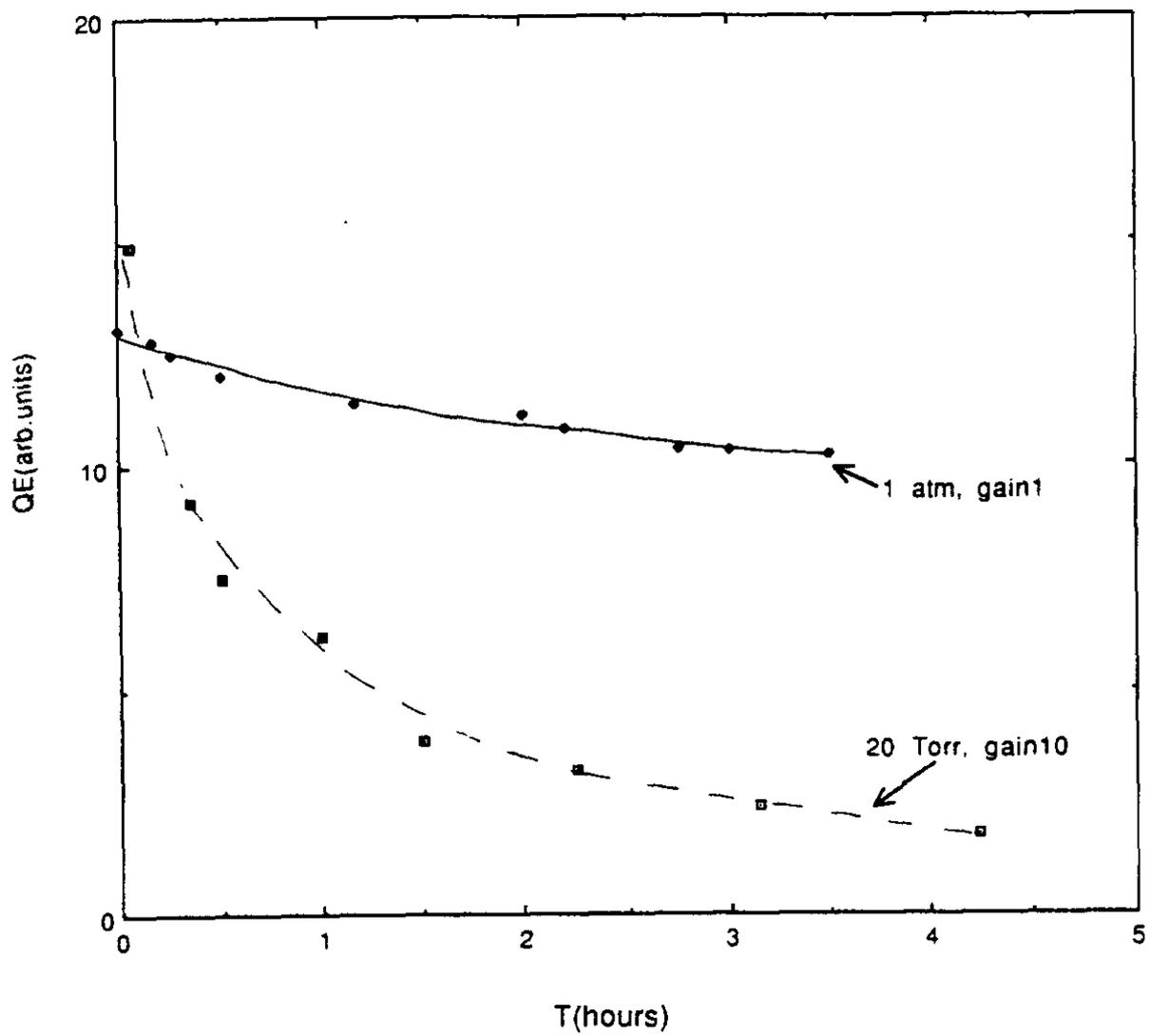


Fig. 4

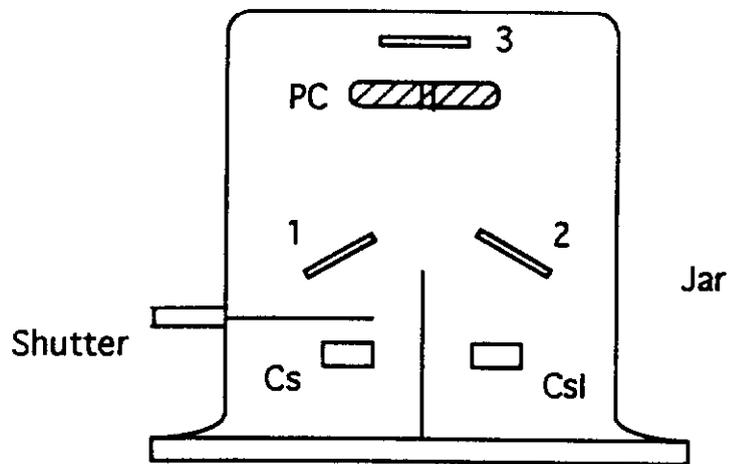


Fig. 5

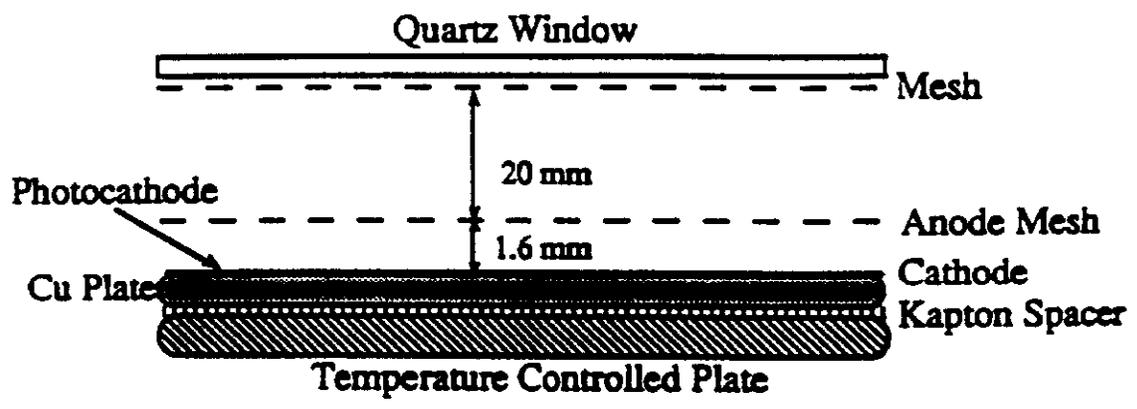


Fig. 6

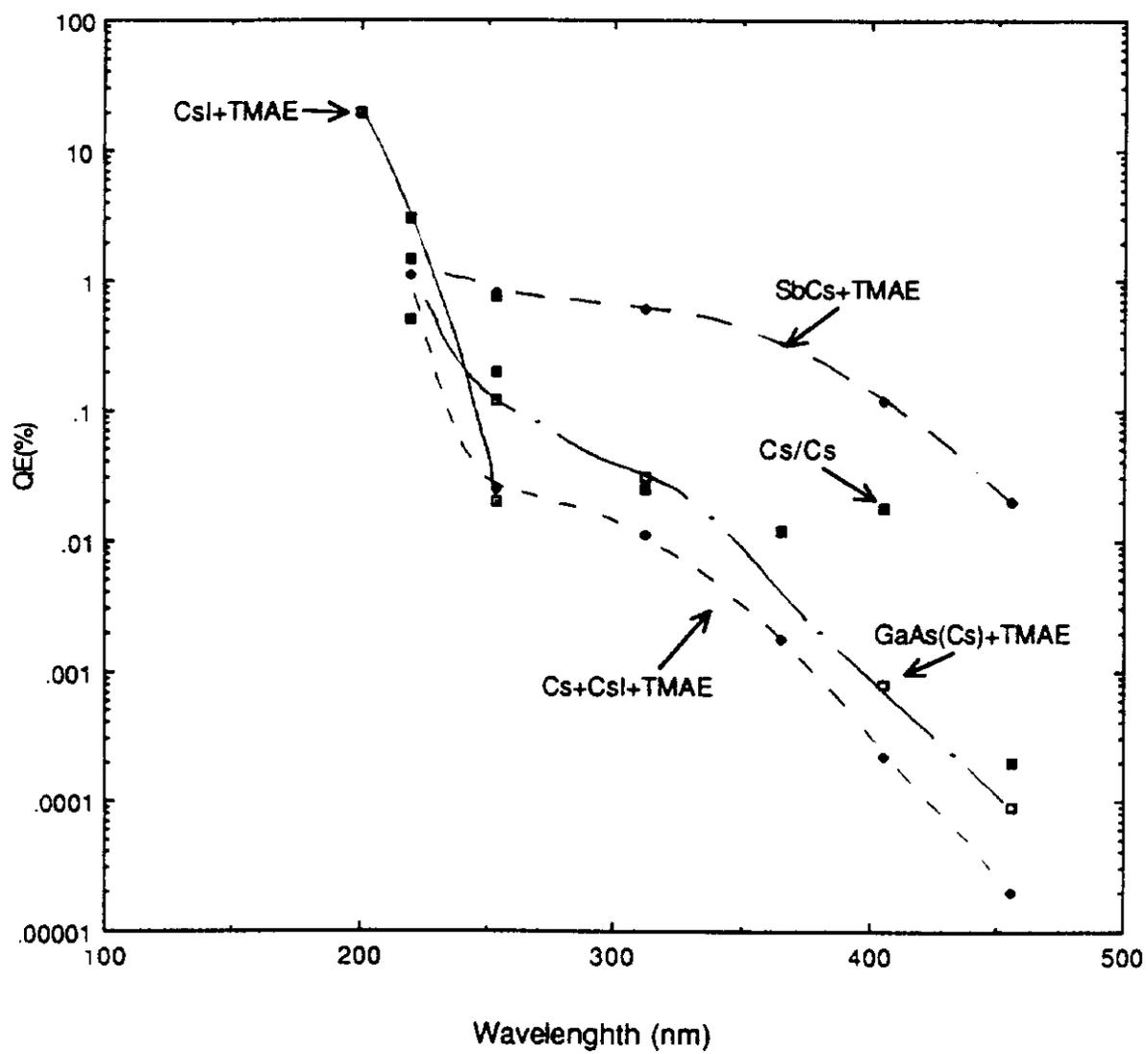


Fig. 7

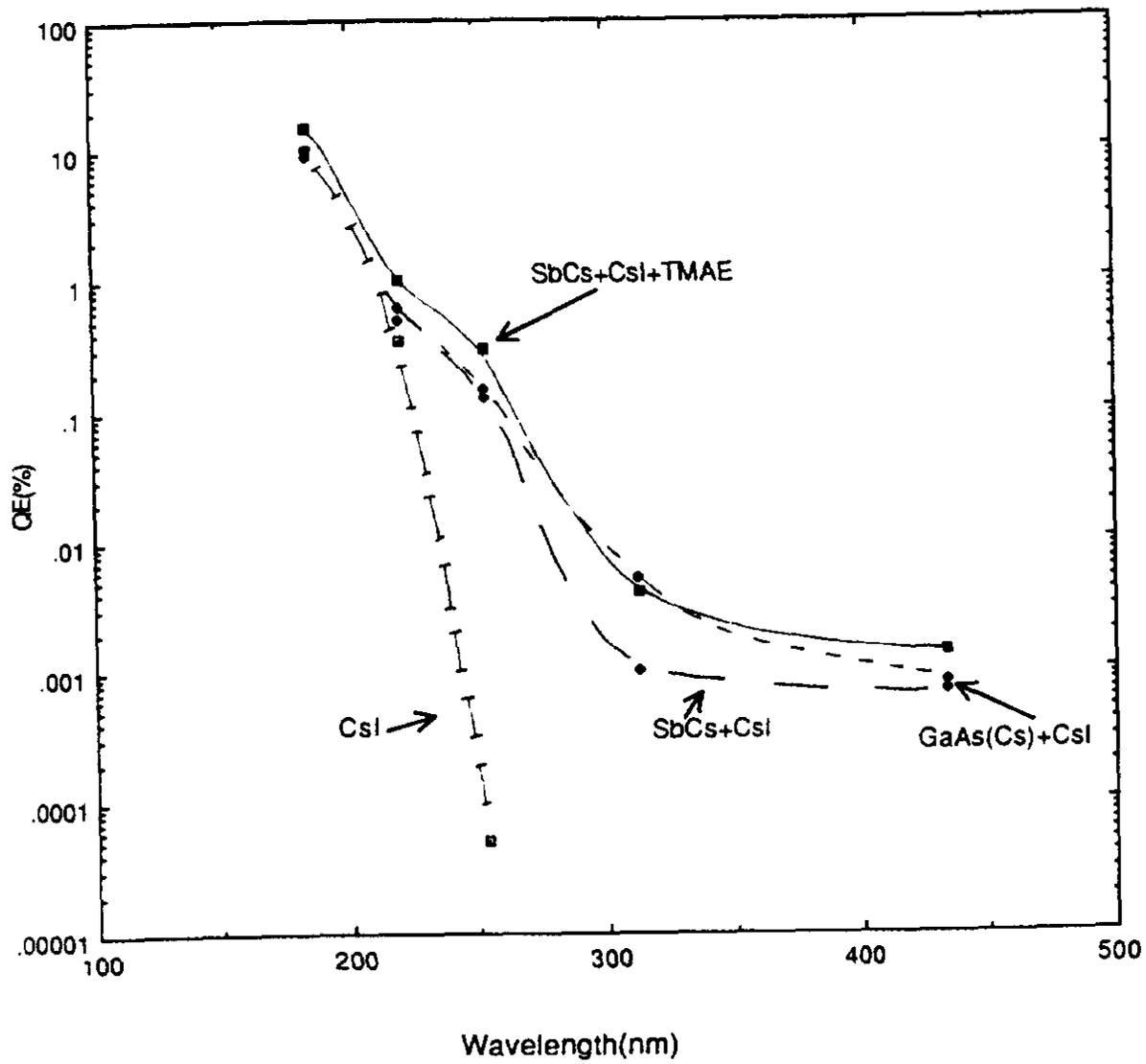


Fig. 8