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Gaseous Photomultipliers for the Readout of Scintillators and Detection Cherenkov Radiation

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Abstract

The latest achievements in the development of gaseous detectors for registering UV and visible photons are described. Possible modifications of their design for some particular applications such as the readout of crystal scintillators, noble liquids, fibers and for large area Cherenkov detectors are discussed.

1. Introduction

Wire chambers filled with photosensitive vapors [1,2] open new areas in applications such as Ring Imaging Cherenkov Counters (see for example a review [3]), plasma diagnostics [4,5], readout crystal scintillators [6]. Intervals of spectral sensitivity of such detectors are restricted by ionization potentials of gases. Gases with the lowest ionization potentials used in wire chambers are: TMAE [6] and ethilferrocene [4]

Recently many efforts have been made by different groups to develop gaseous detectors of UV and visible photons with solid photocathodes (see for example [6,7] and references therein). Advantages of such types of detectors are: much lower than gas threshold of spectral sensitivity, a very good time resolution (<1 ns), possibility to work with high gas gains (up to 10^5), insensitivity to moderate magnetic fields, and position resolutions of a few mm. In fact these are simple position sensitive gaseous photomultipliers, which can be manufactured in the laboratory. Many different solid photocathodes have been developed and tested[4, 8-11]. Most of the earlier work was done in connection with plasma diagnostics [4, 11, 12] and Ring Imaging Cherenkov Counters [13, 14].

In the present report we describe the latest achievements in the development of gaseous detectors of UV and visible photons, and discuss possible modification of their design for some particular applications such as the readout of crystal scintillators, noble liquids, fibers, and for large area Cherenkov detectors.

2. Detectors with CsI Photocathodes

The first gaseous detectors of UV photons with CsI photocathodes were described in ref.[15,16]. After these publications, due to the collective efforts of different groups, great progress was achieved in the development of these detectors. Today such photocathodes have a high quantum efficiency (QE) for wavelengths <220 nm and excellent aging properties [17]. A few possible fields of applications are described in ref.[18, 19]. In the present report we will concentrate basically on the application in calorimetry.

2.1 BaF_2 Calorimetry

BaF_2 is an excellent scintillator which is radiation hard and has a fast component (0.6 ns decay time) in its emission spectrum. BaF_2 can be produced in large quantities for a low price and this makes it a serious candidate for LHC/SSC type detectors [20]. The spectral sensitivity of the CsI photocathodes matches very well with the BaF_2 fast ultraviolet scintillating component . This suggests a very simple and cheap readout for the BaF_2 calorimeter. Gaseous photomultipliers with CsI photocathodes are stable in time, radiation hard, can be exposed to air and have good time and space resolution. It has been demonstrated that a BaF_2 scintillating detector with such a readout allows one to get a good energy ($<3\%E^{-1/2}$) and position resolution (few mm) [21]. This opens the possibility to build "nonsampling" BaF_2 calorimeter with good granularity and therefore with good e/π and e/γ rejection factors [18, 20-21].

2.2 Noble Liquids Scintillation Calorimetry

A noble liquid scintillating calorimeter is also very attractive for LHC/SSC experiments, because it is fast and radiation hard [23]. In connection to this calorimeter two readout techniques have been considered: conventional (vacuum) photomultipliers (PM) and Si photodiodes. As usual both of these readouts have advantages and disadvantages. For example the disadvantage of the first readout is its sensitivity to magnetic fields and for the second one the high sensitivity to direct particles. Both techniques are very expensive.

We demonstrated recently that the CsI photocathodes immersed into noble liquids can be used for the detection of their scintillation light [24]. This suggests another very simple and cheap readout technique. Unfortunately, the timing properties are still restricted by the fact that photoelectrons, extracted from the CsI photocathode, must drift 1-2 mm in the liquid in order to be collected on an anode mesh. Although with proper shaping of the signal from the electrodes one can get time resolution on the order of tens of ns [25], the short scintillation time of noble liquids has not been explored completely. To overcome this problem, J. Seguinot and T. Ypsilantis have suggested the use of vacuum or gaseous photodiodes with the CsI photocathode [26]. However, preliminary tests showed that at low temperatures the QE of the CsI photocathode in the gas or vacuum drops in time and sometimes the drop is large. It was discovered recently that if the CsI photocathode is covered by a thin layer of liquid Xe or Kr it has 2-3 times higher QE than its original value in vacuum and it remains stable at low temperatures [24]. This allows one to read out the scintillation light of noble liquids with such types of detectors .

To deposit a layer of liquids on the surface of the CsI photocathode it is enough to introduce a small amount of Xe or Kr gas into a cold chamber. Under these conditions the gas will be condensed on the surface. Aprile's group at Columbia University is performing now a systematic study of the timing properties of such a detector. One should realize that a large surface- area detector of scintillation light with a quartz window is not easy to construct and it will not be cheap. The price can be optimized by combining two techniques: conventional PM (or gaseous detectors with the CsI photocathodes covered by a layer of Xe or Kr liquids) and CsI photocathodes immersed inside the liquid . The former will give precise timing information. The latter will provide energy deposit information which can be resolved by proper time shaping of the signal. By taking into account precise timing information and by deconvoluting the observed spectra, it is possible to obtain energy deposition with both good timing and energy resolution.

2.3 Lead-Fibers Cherenkov Calorimeter

For the needs of the NA50 experiment at CERN, a very fast radiation resistant calorimeter was developed based on detection of Cherenkov light produced in quartz optical fibers by the beam particles showering in a lead adsorber (for a review see for example [27]). Usually PMs are used for the readout of such a calorimeter. But for fibers with good transmission (for wavelengths>175 nm) one can use compact gaseous photomultipliers with the CsI photocathodes Since CsI does not react with air, the technology of manufacturing such detectors is rather simple. We have made and tested successfully a prototype of a matrix containing 25 gaseous detectors with the CsI photocathodes having a diameter of 1 mm each (see fig.1) [28]. The design of this detector is similar to that described in ref. [29], but in the present experiments the matrix worked in proportional mode with a gain 10^4. Measurements show that such a detector is few times less efficient in recording Cherenkov light from quartz than a standard PM. On the other hand since our detectors are not very sensitive to magnetic field and direct particles, one can probably use shorter fibers and partially compensate in such a way the loss of sensitivity.

3. Detectors with Cs based Photocathodes

As we mentioned above, the CsI photocathodes are sensitive only to wavelengths <220 nm. This restricts their range of applications. Several groups have made attempts to develop photocathodes sensitive to longer wavelengths [7,10].

Recently, promising results have been obtained with Cs based photocathodes [30,31]. The simplest among them are GaAs(Cs) and SbCs. The advantages of such photocathodes are that they are sensitive to much longer wavelengths than CsI (up to visible light) and the QE values can be close to 10% [31]. The technology of production of such photocathodes is very simple: Sb or GaAs substrates are covered with a thin layer of Cs inside the pumped detector and then the chamber is filled with a clean gas [31]. In preliminary tests stable operation in time was achieved only if a getter was installed inside the chamber, and at low light flux. For photocurrent value $<$fA/cm^2 no degradation of the QE was observed over a period of a few months. Gas gains $\geq 10^3$ can be achieved. At higher light flux (~pA/cm^2) aging of the photocathodes was observed. We succeeded recently to improve the aging properties by a few orders of magnitude (collected charge density ~1mC/cm^2) by covering Cs based photocathodes with a 40-80 nm thick layer of CsI, which played a protective role (fig.2) [28]. More studies are needed to demonstrate the long term efficiency of such technology.

3.1 Crystal Scintillators Readout

Photodiodes have been used for the readout of crystal scintillators for a long time. They are relatively cheap and allow one to get good energy resolution for crystals which emit a lot of light per unit of deposited energy such as NaI, BGO, and others. Unfortunately most of these crystals emit scintillation light with a long decay time and are not radiation hard. Studies done by the "Crystal clear" collaboration identify two new promising candidates for LHC/SSC-type detectors: CeF_3 and Pb_2WO_4 [32]. CeF_3 has high light yield, but is expensive. Pb_2WO_4 is twice as cheap, but emits 10 times less light. It appears that the gaseous photomultipliers with the Cs based photocathode might be ideal for the readout of the Pb_2WO_4 scintillator. They can work at sufficiently high gains and in this way compensate for the relatively low intensity of the scintillation light.

3.2 Micro Detectors for Scintillating Fiber Readout

Gaseous detectors with Cs based photocathodes can be made as small in size as with CsI photocathodes . This feature opens application for readout of scintillating fibers. We have made and tested successfully several small prototypes of such detectors (diameter 1mm) with SbCs reflective and semitransparent photocathodes (see fig.3). Technology of manufacturing such detectors was elaborated earlier [8] and described in detail in ref. [28]. Since the sensitivity of the gaseous detectors with SbCs photocathodes is smaller than for PM or solid state detectors (see fig.4) their applicability is limited to the cases where a lot of light is emitted . Examples of such devices are lead/fiber pre-shower detectors or shower -max detectors. We are planning to test small prototypes of such applications. We are performing also now a long term test of stability of small size sealed gaseous detectors.

3.3. Large Area Cherenkov Detectors

Another important application of the Cs based photocathodes could be for large area Cherenkov detectors, e.g. for air shower studies [33]. Such measurements usually are made with high light backgrounds. Therefore an ideal detector for the measurements of the Cherenkov light from air showers should have a very high QE for wavelengths <250 nm, and almost zero QE for wavelengths >250 nm [33]. In fig. 5 we presented the QE curves of one of our photocathodes, which partially satisfies these requirements. Gaseous detectors with such a photocathode can work at gains up to 10^4- 10^5, high enough for detection single photoelectrons. Another important property of this photocathode is that it can be exposed to air for a few minutes without a strong degradation of its QE. This is a very convenient feature for manufacturing, assembling and everyday operation of these detectors. The largest prototype we have tested so far had a photocathode surface of ~100 cm^2.

4. Conclusions

Gaseous photomultipliers with solid photocathodes are new and promising detectors of UV and visible photons. They have a simple design and can be easily manufactured in a laboratory. They can compete with other detectors, especially in some applications, such as calorimetry, large area Cherenkov detectors and plasma diagnostics.

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Figure captions:

Fig. 1a. Schematic view of a matrix containing 25 gaseous detectors with CsI photocathodes having a diameter of 1 mm each

Fig.1b. Spectral sensitivity of an individual detector of the matrix. The CsI QE was measured with respect to the knowen QE of TMAE and ethilferrocene vapors. Measurements were done at 45^0 between the light beam and the matrix axis.

Fig.2. Changes of QE in time for pure SbCs photocathode and for the SbCs photocathode, covered by a CsI protective layer. Measurements were done in CH_4 (20 Torr) at a gain 10.

Fig. 3. Compact gaseous detectors with CsI photocathodes for readout of individual scintillating fibers.

Fig. 4. QE of SbCs photocathodes manufactured inside sealed gaseous micro detectors. The QE measurements were done with respect to the QE of phototubes R414 and R1187, calibrated by Hamamatsy Photonics France.

Fig. 5. Residual QE of the SbCs+CsI+TMAE photocathode after few minutes exposure to the air.

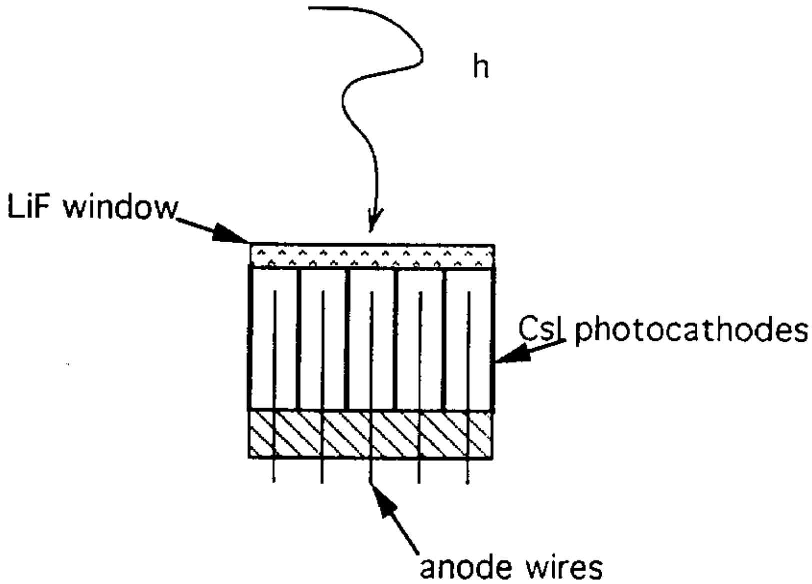


Fig. 1a

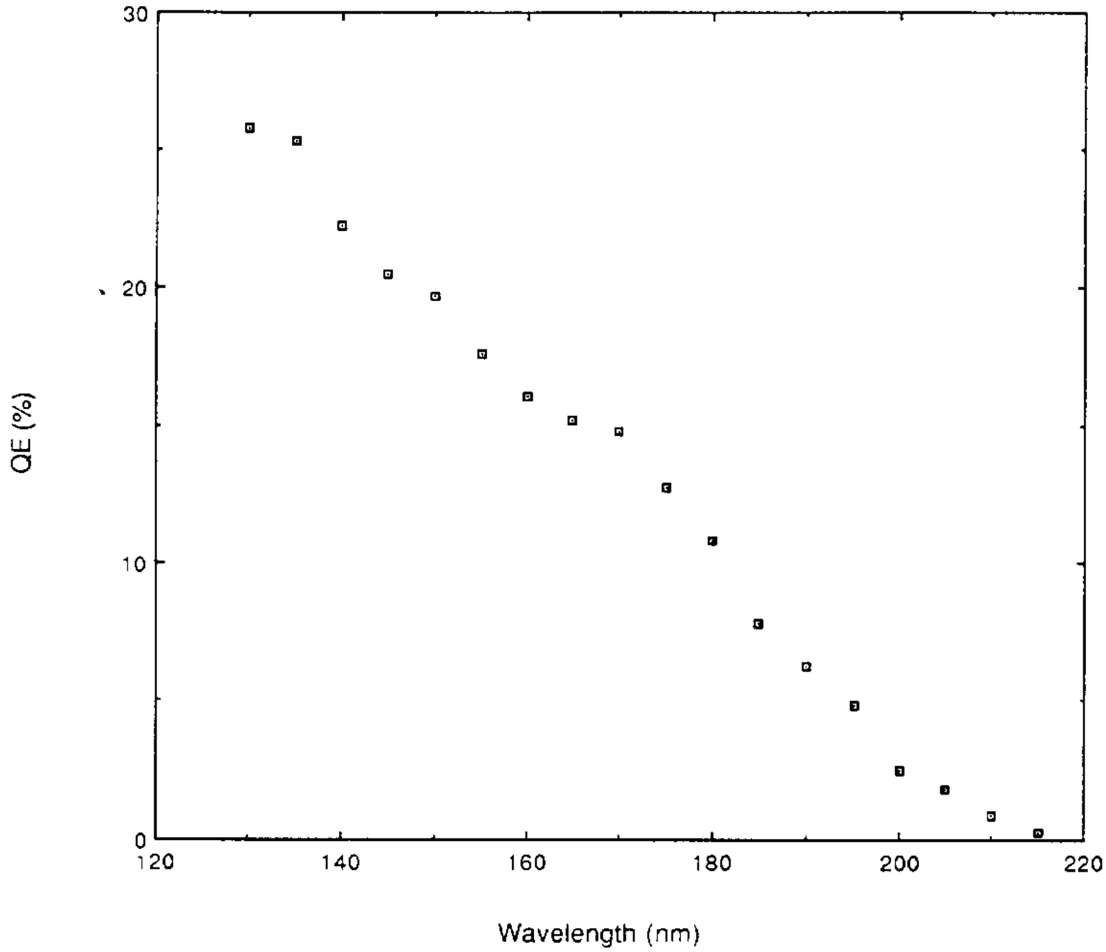


Fig. 1b

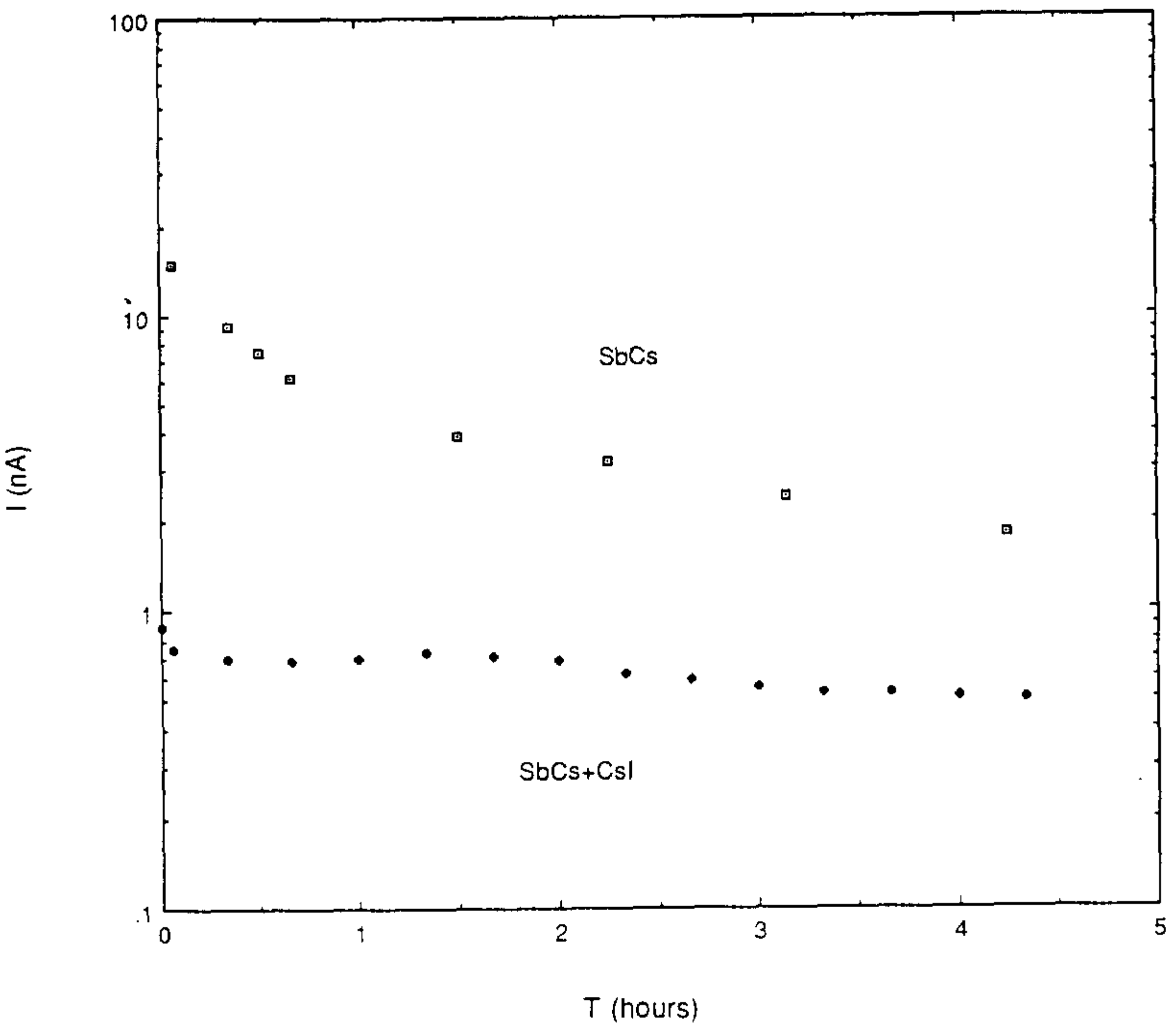
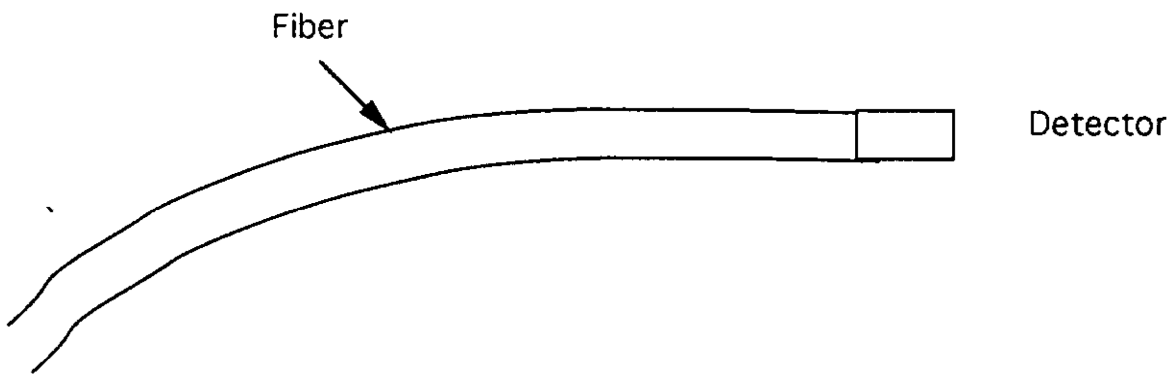


Fig. 2



Detectors with two types of photocathodes:

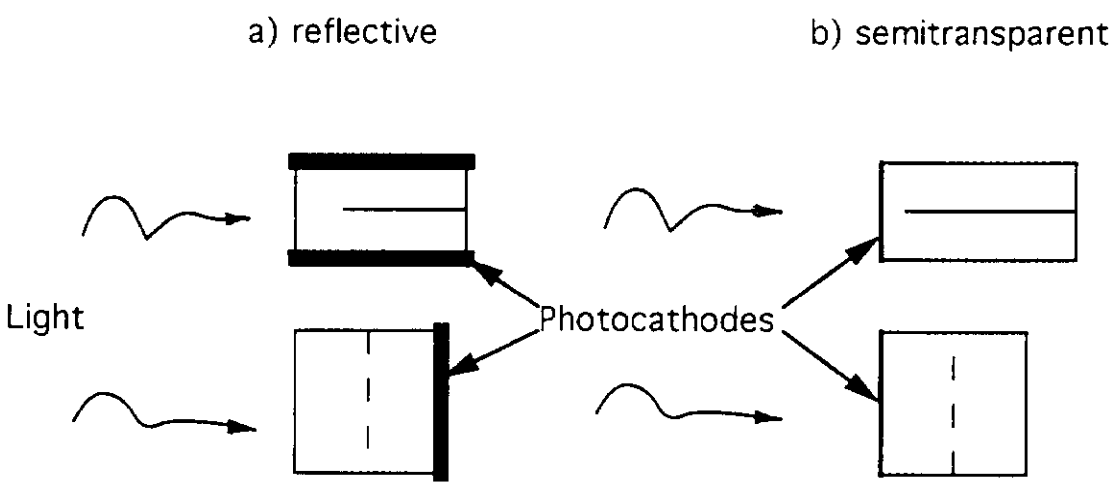
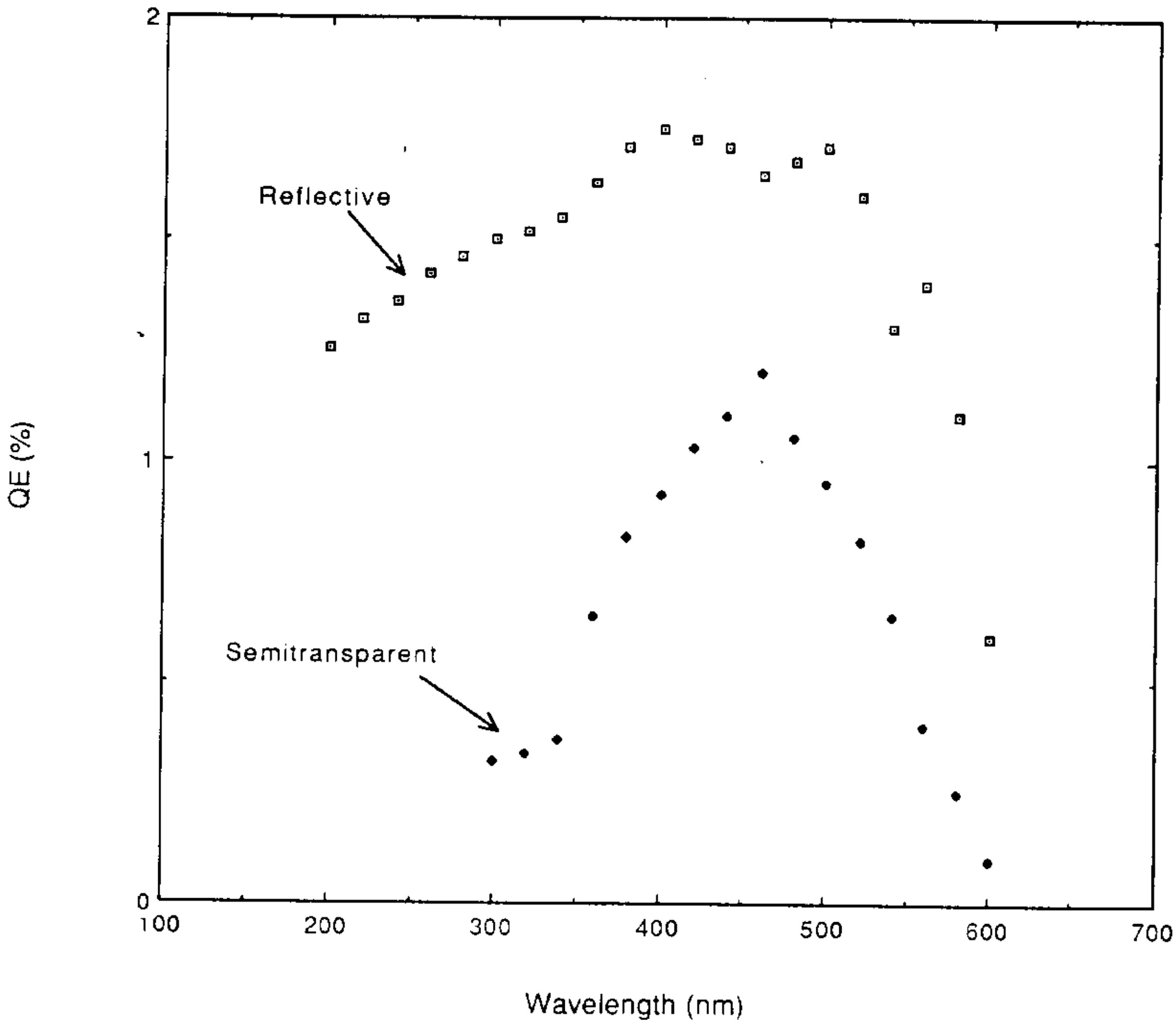


Fig. 3



2
1
0
QE (%)
Reflective
Semitransparent
100
200
300
400
500
600
700
Wavelength (nm)

Fig. 4

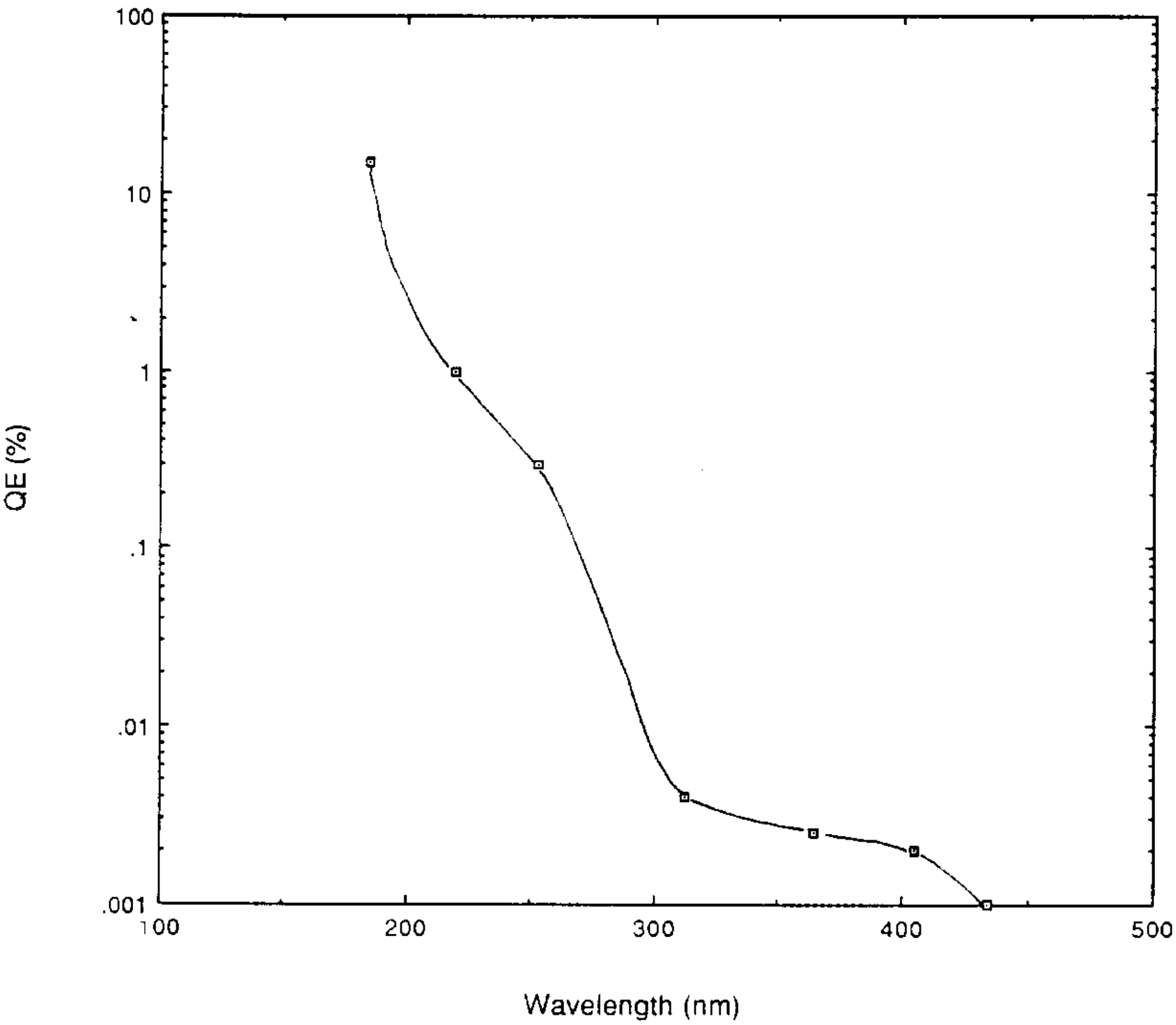


Fig. 5