BARIUM FLUORIDE CRYSTALS AND SELF-QUENCHING STREAMER
CHAMBERS AS A POSITION SENSITIVE GAMMA-RAY DETECTOR

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Summary

We have studied the possibility of using self-quenching streamer chambers to detect photoelectrons produced by a photoconverter in conjunction with Barium Fluoride scintillators.

Introduction

The recent discovery^{1,2} that the scintillator BaF_2 had an ultraviolet (u.v.) component of light opened the possibility of combining it with gaseous detectors where photoelectrons could be observed and the position information measured. This arrangement was successfully tested³⁻⁵ using gases with low photo-ionization potential like TMAE (Tetrakis-dimethylamine-ethylene) and TEA (triethylamine). These photosensitive vapors are absorbed on the metal surfaces of the gaseous chambers, and when the uv photons from the BaF_2 scintillator impinge on them, they emit photoelectrons which are drifted and then amplified at the anode wires in the usual fashion. Chambers of this type have also been tested at low gas pressures⁶⁻⁷ with good results.

In all these tests an important problem that remained was the low efficiency of the device. There are several reasons for this low efficiency. Organic compounds are made up of low Z atoms and the photo-electric cross section is small. If at the same time the region of photoconversion is gaseous or very thin, the fraction of electrons per photon is low and the device is not practical at low energies or when the energy loss in the scintillator is small.

Other photoconvertors have also been tested. Breskin and Chernik⁸ operated successfully a chamber with a solid copper cathode and low pressure gases in two different geometries. As pointed out in that paper, a good efficiency depends not only on the photoelectron creation but also on the efficiency of extraction and drift to the chamber. This effect has been studied in photodiodes of more conventional type⁹ at several gas pressures and it was found that a large fraction of photoelectrons are lost due to early collisions with molecules in the gas of the device.

For these reasons, and with the purpose to obtain a high efficiency detector, we attempted to combine a BaF_2 scintillator with a gas chamber operating at large electric fields and a high fraction of quenching gas like self-quenching streamer (SQS) chamber,¹⁰ as the electric fields at the cathode could be made larger than in the proportional mode. Furthermore, previous results indicated that in this mode, part of the large amplification was obtained through strong absorption of uv photons near the anode.

The high sensitivity to uv light in SQS chambers has been observed previously¹³ but then it was considered more of an inconvenience than an advantage that could be used.

Test with uv light source

Using a collimated source of uv light, we studied the properties of SQS chambers for several geometries and gas mixtures. In Fig. 1a we show the configuration for these measurements. A collimated parallel beam of uv photon ($\lambda_{\text{max}}=280 \text{ nm}$) of 500μ diameter produced by a high pressure Hg lamp was used.

SQS CHAMBER

1a

1b

Fig. 1. a) Configuration to measure the response to uv light in a single wire self quenching streamer (SQS) chamber. The collimated light was moved around the pin hole. b) Response of the chamber for two different anode voltages.

We studied first the electron production efficiency in various regions of our chamber. We found that in the SQS mode of operation, these electrons originate in the gas near the anode, as well as in the cathode walls (aluminum). This was determined by sweeping the uv beam near the single anode, as shown in Fig. 1b. If the photon intensity was too high the large number of ions produced distorted the electric field reducing the efficiency for photoelectron production. These tests were performed with a continuous flow of an Ar and CO_2 mixture at atmospheric pressure. Several relative concentrations had similar results. The pulse shapes observed for several gas mixtures reproduced well results obtained previously using ionizing radiation.

Tests with BaF_2

Three BaF_2 crystals (made by Harshaw Co.) of dimensions $(0.5 \times 2 \times 4 \text{ cm}^3)$, $(1 \times 1 \times 5 \text{ cm}^3)$ and $(2 \times 2 \times 5 \text{ cm}^3)$ were tested with a quartz window phototube (Philips 2020Q) and the uv component of the scintillation was observed using several electron and gamma sources. We measured 1500 ± 300 uv photons/MeV by comparing the charge collected with a NaI(Tl) crystal and correcting for changes in photo efficiency and light collection due to the change in wave length. The decay time of the uv component was less than 1 ns.

We also measured the self absorption of the uv photons in the scintillator. This was done by interposing other BaF_2 crystals between the one scintillating and the photocathode. After correcting for reflection losses in the interface we obtained a half-length of uv absorption of $6 \pm 2 \text{ cm}$. This result indicated that large crystals of BaF_2 will have serious problems with energy resolution. This value is smaller than a similar result published recently.¹⁴

We also tested several plastic films for transparency to uv photons. We found that Aclar (manufactured

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by Allied Fibers and Plastics) had the smallest absorption and was used in all our tests with a thickness of 0.1 mm. The absorption at that thickness for the uv light of BaF_2 was $6 \pm 3\%$.

We also measured the absorption of the uv photons of BaF_2 in Ar, CO_2 and Isobutane at atmospheric pressure, by interposing a gas cell between the scintillator and the quartz window photomultiplier. The absorption was very small and the results are compatible with previously measured values.¹¹⁻¹²

Barium Fluoride with the SQS chamber

We attached a Barium Fluoride crystal to the streamer chamber in the configuration indicated in Fig. 2. The crystal was $2 \times 2 \times 5 \text{ cm}^3$ and was attached to the chamber through an Aclar window of 0.1 mm thickness. The crystal was wrapped in aluminum foil on all faces except the one in contact with the window. The chamber had anode wires of 100 μm diameter gold covered Tungsten separated 6 mm from each other. Several photo-cathodes were tested, including aluminum foil, aluminized mylar, copper foils and gold covered wires similar to the anode wires.

In order to determine the possible conversion in the gas, the chamber had a drift region of 4 cm long which could collect charges in this volume and drift them towards the amplification region by means of an extra set of drift wires as shown in Fig. 2.

To insure that the signals observed in the SQS anode were not due to direct ionization in the chamber gas or walls but to the photons from the scintillator, several precautions were taken. A lead shielding of 2.5 cm thick not shown in the figure separated the source and the gas volume of the chamber. When a ^{106}Ru electron source was used, we interposed a thin plastic scintillator detector and only coincidences with this detector were registered. We also used a movable screen made of opaque thin plastic, which could be inserted to blank the scintillation photons between the BaF_2 and the chamber, but left the geometry of the system unchanged.

Fig. 2. Experimental configuration of the SQS chamber to measure the efficiency of detecting photoelectrons converted from the uv scintillations of a BaF_2 crystal.

All tests were done with a continuous flow of gas (Ar, CO_2 , Isobutane) at atmospheric pressures and fractions measured directly with flow meters. No position information was obtained as yet and all anode wires were interconnected.

The efficiency of the device is defined as the ratio of photoelectrons detected in any anode wire and the average number of uv photons produced in the BaF_2 crystal. Therefore this efficiency includes the transmission of the photons in the medium, the photoelectric effect probability, the extraction of the photoelectron to the gaseous medium and its arrival and multiplication at the anode. It was measured using the previously determined value of 1500 ± 300 uv photons/MeV and the average energy deposited in the BaF_2 crystal. The uncertainty in the efficiency include the uncertainty

Table I

Source	Photocathode	gas mixture	HV	Cathode bias	Efficiency
		(Iso, CO_2 , Ar)	(kV)	(kV)	(%)
^{106}Ru	Au	30,30,30	5.4	—	0.3-1.0
^{106}Ru	Au	40,30,30	5.2	—	0.2-0.9
^{60}Co	Au	30,30,30	5.4	—	0.1-0.8
^{60}Co	Au	0,100,40	5.3	—	0.1-0.9
^{106}Ru	Au	0,100,40	5.3	—	0.2-1.1
^{106}Ru	Au	0,80,20	5.2	—	0.2-1.0
^{106}Ru	Au	50,0,50	5.3	—	0.3-1.2
^{106}Ru	Al	0,50,50	5.2	-0.5	0.1-0.8
^{106}Ru	Al	0,80,20	5.2	-1.0	0.3-0.8
^{60}Co	Al	0,80,20	5.2	-0.5	0.1-0.7
^{60}Co	Cu	0,80,20	5.2	-0.5	0.6-1.4
^{60}Co	Cu	0,80,20	5.2	-1.0	0.5-1.2
^{60}Co	Cu	0,50,50	5.4	-0.5	0.4-1.1
^{60}Co	Cu	0,50,50	5.4	-1.0	0.5-1.3
^{60}Co	—	0,50,50	5.4	—	0.1-0.3
^{106}Ru	—	0,50,50	5.4	—	0.0-0.2

of the photoefficiency of the crystal, the statistical uncertainties from background subtraction and geometrical effects. In all cases the anode signals were of the saturated type with 30 to 100 mV amplitude (in 50 Ω) and 30 to 200 ns duration.

The results are summarized in Table 1. In the case where no photocathode was used, a black insulator was interposed between the cathode wires and the photocathode. This was done to measure the conversion in the gas. For these measurements an electric field of 300 V/cm was applied to the drift region. In the cases of gold photocathode, they refer to the cathode wires of the SQS chamber.

Conclusions

These measurements indicate that solid photocathodes can be used in gaseous chambers operating in the saturated mode. However the efficiency of the device is still too small to be used in low energy devices, and it is lower than the value reported by Anderson.^{7,3}

Changes in the electric field at the photocathode have small effects in the efficiency. Photoconversion in the gas contributes less than 20% in all cases and the rest of the photoelectrons originate in the photocathode. Other photocathodes are presently being studied.

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