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Can TMAE photocathode be used for high rate applications ?*

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ABSTRACT

The paper explores the problems associated with wire aging, charging effects and self-sustaining cathode currents in the TMAE based photo-detectors.

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INTRODUCTION

It is generally believed that anode wire aging is the most serious problem encountered in TMAE (Tetrakis dimethylamino ethylene)-based Cherenkov ring imaging detectors.[1] Although charging effects and self-sustaining cathode currents have not been studied systematically, there is concern that they too could become significant over a long period of time.

TMAE, as are all photosensitive materials, is an insulator, whose insulation properties improve with purity. It coats all surfaces within the chamber containing it. Moreover, TMAE-based gas systems carefully remove water, which would tend to increase the conductivity of surface films. In the presence of a large background, positive ions deposited on the cathode surface could cause a large increase in the electric field across such an insulating layer, which in turn, may cause emission of electrons from the cathode (Malter effect). If the efficiency of production of the secondary electrons is high enough, the chamber might then go into self-sustaining current mode.

As a result of such concerns, a study of chamber response to the presence of large background was undertaken as part of a program to develop a Fast Drift CRID detector[2] for possible particle identification at the B-factory at SLAC.

It was hoped that such study might also result in a better understanding of the CRID detectors[3] which have been in use since 1991 for particle identification at SLD experiment at SLAC.

1. SELF-SUSTAINING CURRENTS

1.1. High rate tests with a small chamber.

The experimental setup is shown in Figure 1. The chamber used a nickel plated cathode with 33 or 7 μm diameter carbon anode wire. Radiation was provided by an Fe^{55} source. The threshold for triggering a self-sustaining current was measured as follows : (a) the chamber was irradiated for a few seconds; (b) the source was removed to check for the presence of a self-sustaining current; (c) if the current was not excited, the source was returned to the original location, the voltage raised and the sequence repeated. Once a steady current was excited, it could only be stopped by shutting off the high voltage for 10-20 seconds. This test was repeated many times using different cathodes and wires, and the lowest detected self-sustaining current threshold from all different tries is the one quoted. "Used" cathodes from previous wire aging tests were chosen so as to avoid optimistic results.

Table 1 shows the results. They clearly indicate dependence of the threshold on the gas, i.e. TMAE is not the only factor. Helium-based gases with TMAE are worst. Among the hydrocarbon carrier gases, iC_4H_{10}+TMAE is the worst, and CH_4+TMAE is the best. Pure CF_4+TMAE is worse than 80%CF_4+ 20%iC_4H_{10}+TMAE. The SLD CRID gases, C_2H_6+ TMAE (Barrel) and 15%CO_2+ 85%C_2H_6+ TMAE (Endcap), show an average behavior. A necessary condition for obtaining a steady self-sustaining cathode current is $G.\eta > 1$, where G is wire gain and η is

MASTER

efficiency to produce a secondary electron on the cathode surface. In these tests, the wire gain was typically $G>10^5$ and therefore $\eta<10^{-6}$.

It should be mentioned that even below threshold the chamber can draw a tiny current which subsides slowly. It can take seconds after the source is removed before the current reaches zero . This current may be as low as 0.5-1 nA, and as a result can be easily overlooked.

1.2. CRID detectors at SLD after four years of operation with TMAE.

The power of the CRID TPC[3] is that it can image not only physics events but also its internal behavior with excellent 3-dimensional reconstruction capability and single electron sensitivity.

It was discovered that running UV fiber calibration data continuously over several years caused damage to cathodes corresponding to wire locations aligned to the UV fiber fiducials. The damage would show up as a burst of charge every 15-20 minutes. Figure 2a shows the top view of a TPC and indicates that several wires have a large number of hits. The fact that they are reconstructed as distributed along the drift direction does not necessarily mean that they are coming from the high voltage end of the drift box. The evidence is that they can occur both on a detector cathode and on a high voltage electrode of the drift box. Figure 2b shows one example of a burst imaged in a localized cathode spot. In this case it probably comes from the high voltage end. All bursts lasted longer than one Barrel CRID readout cycle, ~35 μsec, and less than ~0.5 sec corresponding to nearest possible trigger, i.e. the burst "extinguishes" itself - see Figure 2c. In other words, the condition $G.\eta>1$ was not reached in this case. The burst consists of many single electron pulses, as shown in Figure 3. The burst was not sufficient to trip the high voltage power supply, which has a 600 nA trip threshold. In fact it was not noticed until several 7 μm wires broke; these were presumably weakened by the local heating which occurs during such bursts. If a larger anode wire diameter had been chosen for the detector, it is probable that this effect would have gone unobserved.

This phenomenon is clearly not due to self-sustaining currents, but rather it resembles a charging effect. The UV lamp trigger rate was 120 Hz, and resulted in a photoelectron effective rate of ~10/cm/s along the wire length in some locations (with exception of SLC background muons passing parallel to TPC axis, this was typically highest charge density per wire length). The 15-20 minute period corresponds to several time constants associated with charging of the film, where $RC = \varepsilon_r . \varepsilon_o . \rho_{film}$, $\varepsilon_r \sim 4$ and $\rho_{film} > 10^{15} \Omega$ cm. For a wire gain ($\overline{G} \sim 1.5\times10^5$) and the 15-20 minute charging time, a charge density of more than 10^9 ions per few mm square of the cathode surface could be reached, and this would result in fields of more than 100 kV/cm across the insulator (if the film is sufficiently thin (<100 Å), the "static" behavior of the chamber would not be altered). Such values could be above the dielectric strength of the film, and a breakthrough of electrons could occur. In addition, such fields begin to be significant for the Schottky reduction of the work function of the cathode metal , i.e. the cathode could become photo-sensitive. This somewhat unfortunate state of affairs lasted for about two years, and represented the dominant

dose in certain regions of the chambers. Bursts have not been observed while the UV lamp is switched off. After the problem was discovered, the UV fiber trigger rate was reduced by a factor of 2000, and this yielded a reduction of the burst rate by more than a factor of 20.

The total charge dose from the UV source before the first bursts were discovered was estimated to be only about 2×10^{-7} C/cm, which is an exceedingly small amount. This threshold, both as integrated charge or instantaneous rate, is much lower than has been observed in any of the small tests described in the previous section. This raises a question as to whether any small test can really simulate the phenomenon properly. It could be that a long term exposure to very pure TMAE in a system which has not been opened to moisture for years, is the condition which is difficult to simulate in a small test.

It is natural to ask whether any of the CRID detectors ever reached a steady self-sustaining current condition $G.\eta>1$ in the past. Two such cases have been observed, one of which occurred at an early R&D stage in the lab. The detector did not have TMAE at that point, although it had been exposed to it prior to the test. It was subjected to a very large UV light flux, which caused a background of ~6 nA per detector or about 0.1 nA per cm of wire. After a few minutes the overall detector current jumped to about 700 nA and remained steady even if the source was removed. The second case was observed during early operation at SLD while the gating circuit was on. One TPC established a steady current condition. It is believed that during the gating operation positive feedback can be created between anode and gating wires, if the gating wire has some insulating deposits.

2. WIRE AGING TESTS

2.1. Brief review of the "old" TMAE results.

These tests were performed in the apparatus shown in Figure 1.[1] The results were surprising. The wire aging rate was extremely rapid, much more so than that observed in other gases - see Figure 4a. The tests found a number of interesting dependencies : (a) the wire aging rate decreased with an increase in the complexity of the hydrocarbon molecule of the carrier gas; (b) it decreased with an increase in the diameter of the anode wire; (c) it did not seem to depend on the TMAE concentration, gas flow, anode material, detector temperature or source intensity; (d) the anode wire deposits appeared to consist of a thin film which reacted with air to form droplets after the chamber was opened (these droplets could be easily washed by alcohol, but if left on the wire, they would slowly increase in viscosity, and after a year would have the consistency of honey); (e) the anode wire aging deposits could be easily evaporated by passing a small current of about 10 mA through the 7 μm diameter carbon wire.

2.2. The "new" TMAE wire aging results.

The new measurements were performed recently in the same apparatus. However, a new condition was introduced in the new tests, namely the TMAE was purified by additional pumping

(a procedure currently followed for the CRID detectors[3]). The TMAE used in the old tests was only washed in water and then filtered. In addition, all new tests used a higher TMAE concentration by running the TMAE bubbler at 40°C and the detector at 50°C.[2]

Figure 4b shows a comparison of old and new measurements with C_2H_6+TMAE gas and a wire diameter of 7 µm . The new results indicate a similar initial drop in gain, followed however, by a considerably higher plateau than observed in the old CRID tests; Figure 5a shows a similar result with 33 µm wire, however, the new results show better aging behavior. This difference is not thought to be due to a difference in the TMAE bubbler or detector temperatures, because this was not seen to be a factor in the old tests. It may be due to a difference in the TMAE purity.

Figures 5a,b show the new results with anode carbon wire of diameter 33µm for the conditions of the Fast Drift CRID. It is observed that 15% CO_2+85% C_2H_6+TMAE gas has a faster aging rate than C_2H_6+TMAE gas, and that iC_4H_{10}+TMAE is worse than the He+iC_4H_{10}+TMAE gas mixture. A 50% He+ 50% C_2H_6 +TMAE appears to be the worst helium-based gas.

CONCLUSIONS

1. It may be necessary to add a small amount of water (~20ppm) to prevent charging effects in TMAE systems which are not opened to air for years, and which have been designed so carefully to remove water in the first place. The TMAE itself could be of significantly higher purity in the final system compared to that used for the initial testing. The signature of the problem is not necessarily a continuous standing cathode current, but rather a sporadic burst followed by many single electron pulses. This behavior may even go unnoticed, since the burst is typically well below the trip level. Small tests do not simulate this problem properly, perhaps because the test detector is frequently opened to air. Care should therefore be taken in extrapolating small-test experience to a large system operating at high rate. The problem may be relevant for all photo-detectors, since photo-cathode materials are generally good insulators.
2. Self-sustaining cathode currents may be the most significant problem causing rapid deterioration. This paper offers no good solution, except to try a different carrier gas such as methane; however, protection against the accumulation of large charge doses should be designed into the design of the high voltage shut-off system. New fast and highly segmented electronics circuits recognizing this behavior are needed.
3. Anode wire aging is not so threatening if anode wire of larger diameter is used. A gain drop of 30-50% after few mC/cm could be compensated for by adjusting the high voltage. In high rate applications, the use of carbon wires is recommended in conjunction with a system for heating the wires by sending a small current through them.
4. Helium-based gases do not show an improvement in terms of wire aging or self-sustaining current threshold.

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REFERENCES

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[3] A. Abe et. al., Nucl.Instr.&Meth., A343 (1994) 74.

FIGURE CAPTIONS

1. Experimental setup used to perform the tests of wire aging and rate dependent effects.
2. Observation of the initial state of excitation of self-sustaining currents, respective bursts of pulses in Barrel CRID TPC (x_{TPC}, y_{TPC}, z_{TPC} are wire address, charge division and drift directions) : (a) reconstructed hits along the edge of the TPC as seen in the top view of the drift box, (b) the same group of hits as seen looking into the drift box, (c) the bursts lasted longer than one readout cycle (~35 µsec), and less than ~0.5 sec corresponding to the nearest possible trigger.
3. Burst of pulses as seen on both sides of the wire. The image in Figure 2b was reconstructed using this analog information.
4. "Old" TMAE wire aging test results[1] with 7 µm wire diameter (bubbler at 27°C; detector at 40°C) for : (a) CH_4+TMAE ; (b) C_2H_6+TMAE; in (b) the "new" results for the same gas are also shown (bubbler at 40°C; detector at 50°C).
5. "New" TMAE wire aging test results with 33 µm wire diameter (bubbler at 40°C, detector at 50°C) for : (a) C_2H_6 (open downward triangle, closed downward triangle, closed circles), CH_4 (closed diamond, closed squares), 15% CO_2+85% C_2H_6 (closed upward triangles, open upward triangles) and compared to "old" results for CH_4 gas (open squares, bubbler at 40°C; detector at 50°C); (b) 80% He+20% iC_4H_{10} (closed circles, closed downward triangles), 60% He+40% iC_4H_{10} (open squares), iC_4H_{10} (closed squares), 50%He+ 50% C_2H_6 (open diamonds).

Table 1 - Threshold current density [nA per 5 mm of wire length] necessary to excite a steady self-sustaining cathode current (33 μm diameter carbon wire, nickel plated aluminum cathode).

Gas TMAE : bubbler at 40°C, wire at 50°C	Threshold current density
CF_4+TMAE	≥ 200 nA
80% CF_4+20% iC_4H_{10}+TMAE	≥ 1200
CH_4+TMAE	≥ 350
C_2H_6 +TMAE	≥ 200
iC_4H_{10}+TMAE	≥ 140
15% CO_2+85% C_2H_6+TMAE	≥ 200
50% He+50% C_2H_6+TMAE	≥ 100
80% He+20% iC_4H_{10}+TMAE	≥ 120
60% He+40% iC_4H_{10}+TMAE	≥ 150

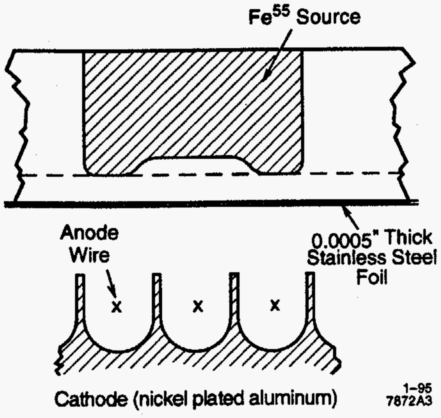

Fig. 1

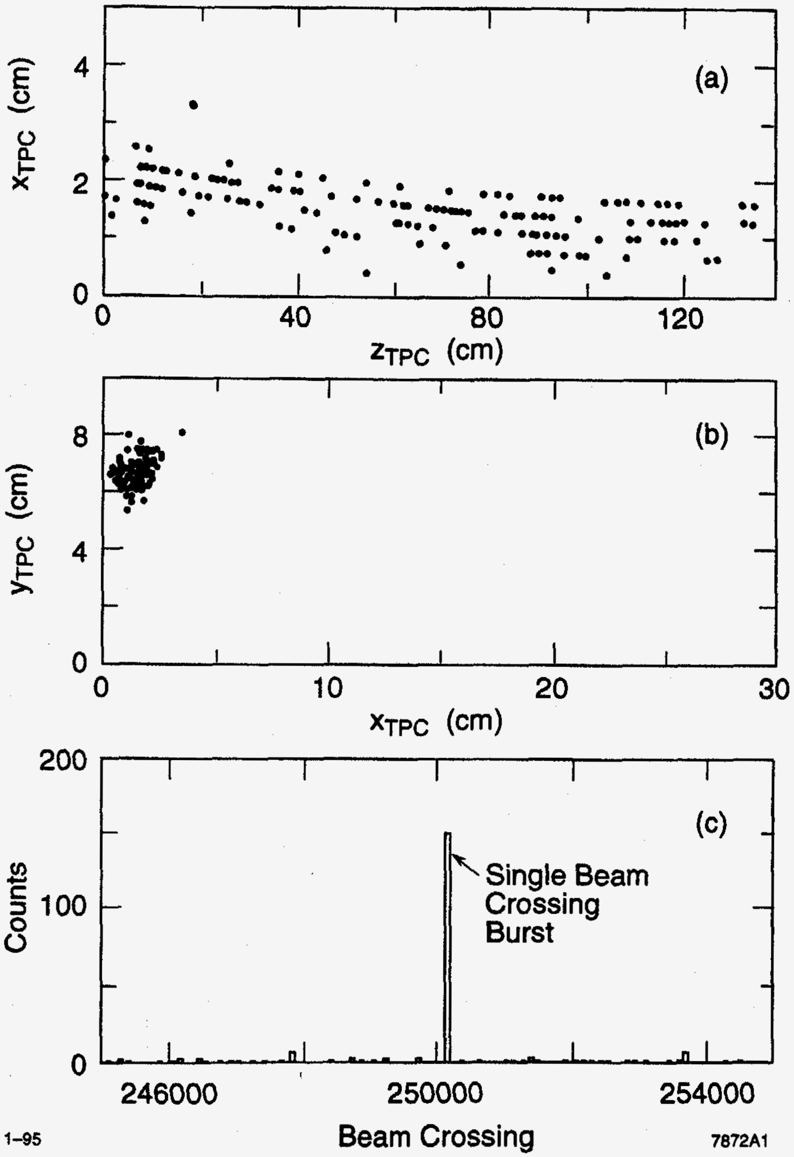

Fig. 2

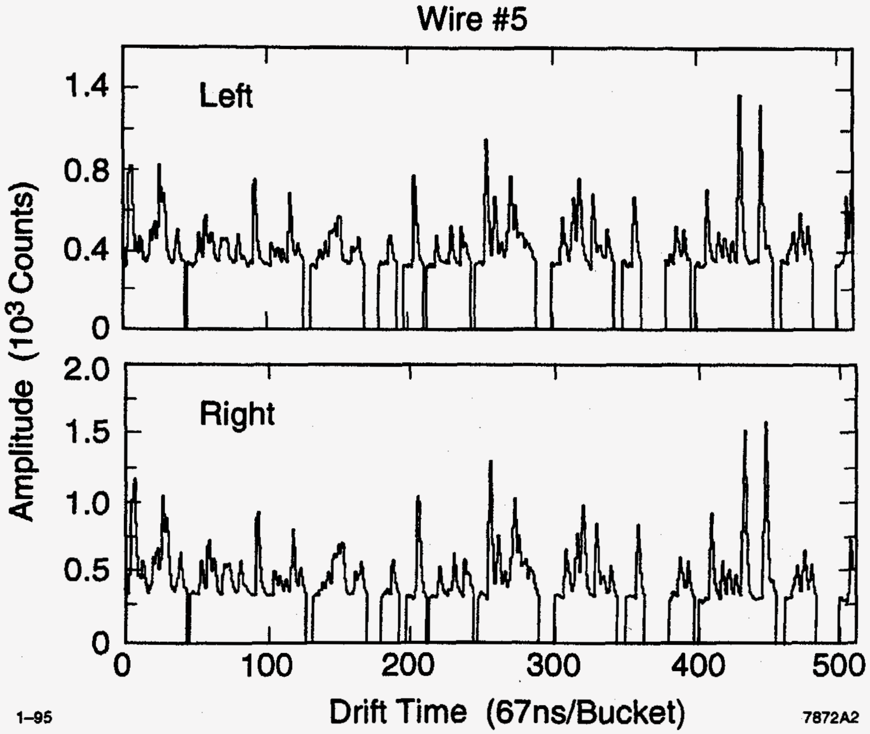

Fig. 3

DISCLAIMER

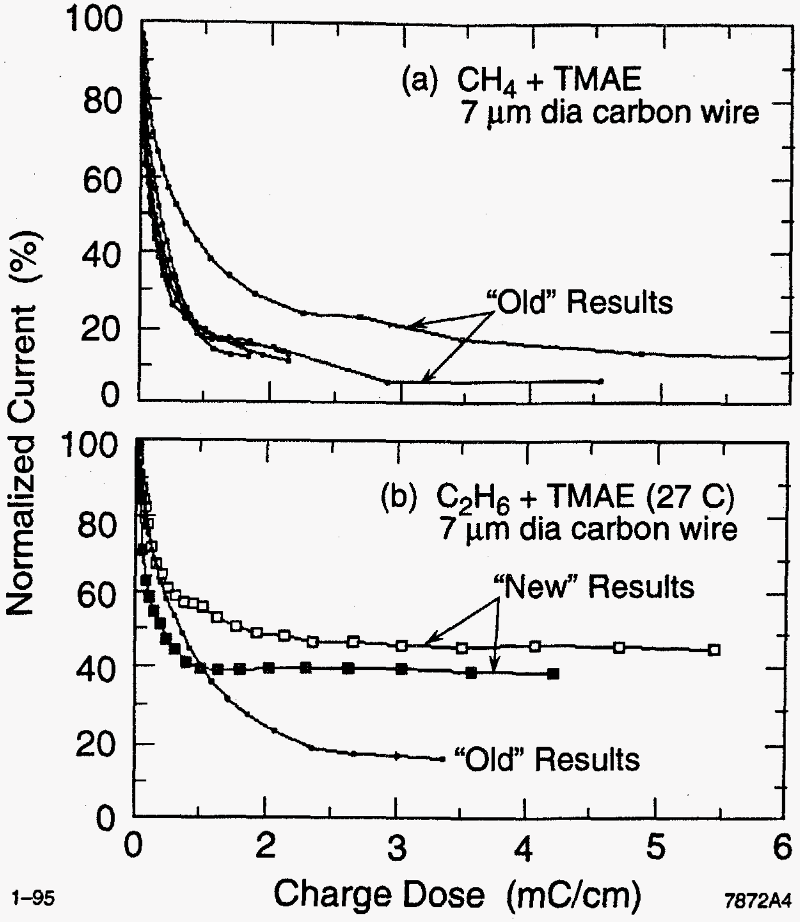
(a) CH_4 + TMAE
7 μm dia carbon wire
"Old" Results
(b) C_2H_6 + TMAE (27 C)
7 μm dia carbon wire
"New" Results
"Old" Results
Normalized Current (%)
100
80
60
40
20
0
0
2
3
4
5
6
Charge Dose (mC/cm)
1–95
7872A4

Fig. 4

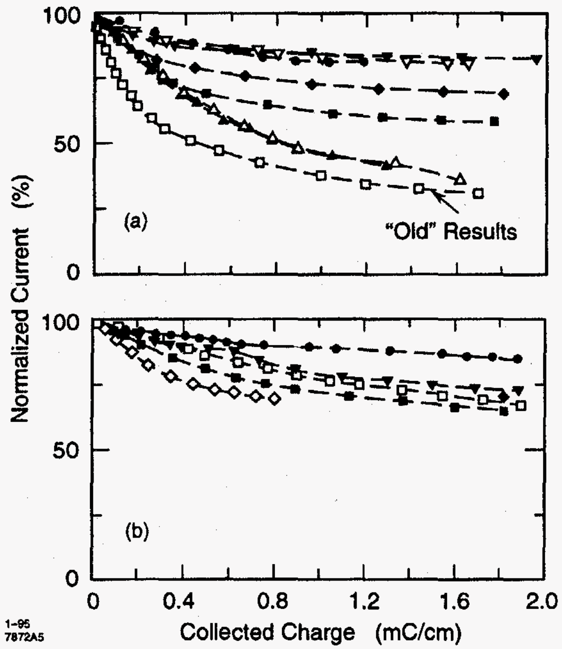
(a)
"Old" Results
(b)
Normalized Current (%)
100
50
0
0
0.4
0.8
1.2
1.6
2.0
Collected Charge (mC/cm)
1-95
7872A5

Fig. 5