WHICH GASEOUS DETECTOR IS THE BEST AT HIGH RATES?

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Abstract

We report results from a systematic study of breakdown limits for various high rate gaseous detectors: PPAC's, MGC's, diamond-coated MSGC's, MICROMEGAS, CAT. It was found that for all these detectors, the maximum achievable gain, before breakdown appears, drops dramatically with incident flux, and is sometimes inversely proportional to it. Further, in the presence of alpha particles, typical of the backgrounds in high-energy experiments, additional gain drops by 1-2 orders of magnitude were observed for some detectors. We discovered that breakdowns at high rates occur through what we have termed an "accumulative mechanism", which does not seem to have been previously reported in the literature. Results of these studies may help to choose the optimum detector for given experimental conditions

1. Introduction

Future high-luminosity experiments make serious demands on detector technologies and have prompted a chain of inventions of new high-rate gaseous detectors: MSGCs[1], MGCs[2], CAT[3], MICROMEGAS[4] and GEM [5]. Due to the extremely tight time scales involved, some these detectors were almost immediately adopted for the large experiments at CERN and elsewhere. The aim of this work is to perform an independent systematic study of the breakdown limits of these and other gaseous detectors recently chosen or considered as candidates for high-luminosity applications.

2. Experimental set -up

The experimental set up was described in detail in Ref.6 and is presented schematically in Fig.1. It consists, in essence, of a test chamber inside of which the various detectors under study were installed. We investigated the rate behavior of the following detectors: PPAC's, MGC's, diamond-coated MSGC's, thin-gap PPAC's, CAT and MICROMEGAS. The detailed description of their designs are given in Refs.6 and 7. In some measurements a MWPC was also used. This device had 20-micron anodes on a 3-mm pitch with a 4-mm gap between cathode planes, the lower of which was a solid metallic sheet and the upper was a 80% transparent mesh with a drift space above if necessary. Additional studies were done combining all the above devices with preamplification structures: GEM, PPAC or MICROMEGAS-type [6,8]. Most of the measurements were done in Ar-based mixtures at pressure of 1 atm although other mixtures and pressures were occasionally tested [6]. As sources of primary ionization, we used an X-ray gun with variable photon energies (6, 17 or 30 keV), and alpha particles collimated perpendicular to the detector surfaces. The full procedures for gain calibration and the measurements of breakdown limits are described in Refs.6 and 9.

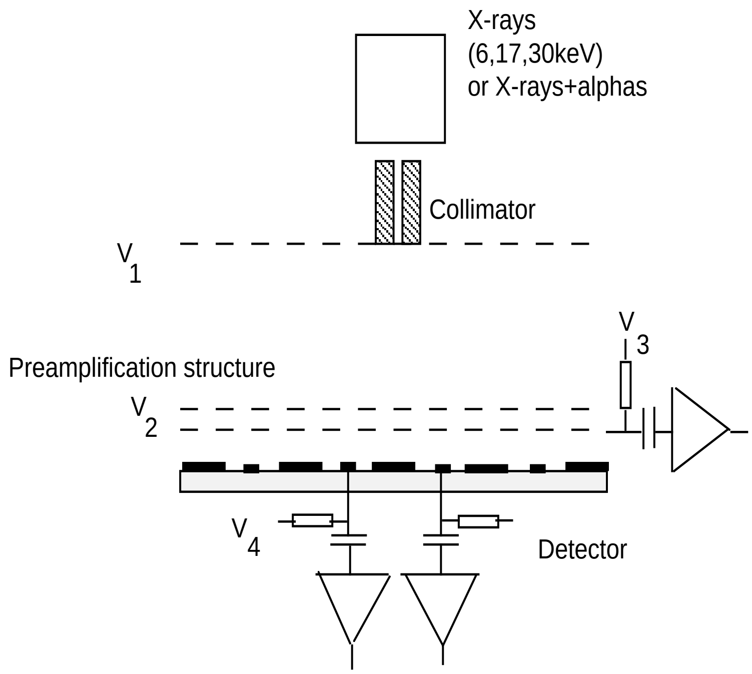

Fig. 1. Schematic drawing of the experimental set-up.

3. Results

The main results of our studies are summarized in Figs.2 and 3. In Fig.2 we plot the maximum achievable gain before the breakdown appear under irradiation with 6 keV x-rays. As one can clearly see, for all detectors tested the maximum achievable gain drops with rate. The highest gains were obtained with MSGC's with preamplification structures [6] , MICROMEGAS [10] and thin gap PPAC's [9]. It is interesting to note that the use of any preamplification structure for MICROMEGAS, thin gap PPAC's or PPAC's did not give any significant increase of the total gain [6,9]. This is thought to be due to charge-cloud expansion in the preamplification structure which has dramatic effect on the confined avalanche of the MSGC, but a much smaller effect on the broader parallel-plate-type avalanche of MICROMEGAS and PPAC's (see Ref.8 for more details). During these studies we discovered an interesting features of the MICROMEGAS and thin gap PPAC detectors: the discharge which appears at breakdown is self-quenched, that is, the energy released in the spark is much less than that stored by the detector's capacitance [9]. Our measurements also show that the energy released in the spark is much less than in conventional

PPAC's which have even lower capacitance. This feature makes them unique for many applications.

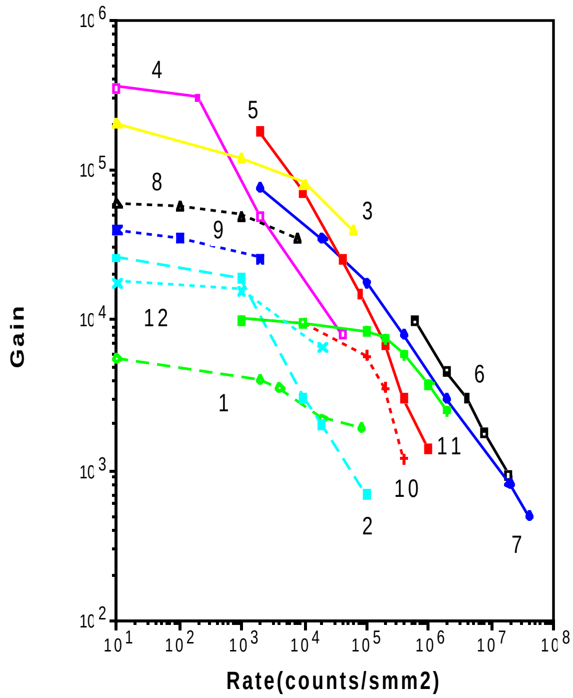

Fig. 2. The maximum achievable gain (curves 1-7), as a function of X-ray flux, for various detectors: 1) diamond-coated MSGC with 0.2 mm pitch, 2) diamond-coated MSGC with 1-mm pitch, 3) MSGC (1) combined with GEM, 4) MSGC (2) combined with GEM, 5) PPAC with 3-mm gap, 6) MICROMEGAS [10], 7) thin gap (0.6mm) PPAC [9], 8-12) space-charge gain limit as a function of rate for the MWPC: 8-10) replotted from ref. [12-14],11) thin gap MWPC [14]. In the case of 11 and 12 the value of gas gain is estimated from data given in [14]. 12) our measurements for MWPC. The curve for CAT is close to that of the curve 1, and so is not plotted to simplify the figure.

One should note that the absolute value of the maximum achievable gain before breakdown occurs depends, of course, on the gas mixture and this may give a powerful parameter for detector optimization. However, the tendency is that for all mixtures tested, the maximum achievable gain drops with rate. The maximum achievable gains for the MGC and MSGC never exceed $2x10^4$ [11] and for MICROMEGAS, $2x10^5$ [10], even with optimized gas mixtures. When combined with preamplification structures, however, the MSGC in an (MSGC+GEM) configuration gave gains of $2x10^5$-10^6 in all gas mixtures tested, which made it superior to all other devices.

For comparison, Fig.2 also shows data for conventional and thin-gap MWPC's [12,13,14]. In these cases, the high counting rate does not trigger any breakdowns, but lowers the amplitudes due to an accumulation of space charge. Therefore, Fig.2 does not shows the maximum gain, but the changes in amplitudes due to the space charge effect. It is perhaps surprising to see that these detectors have reasonable rate capabilities too.

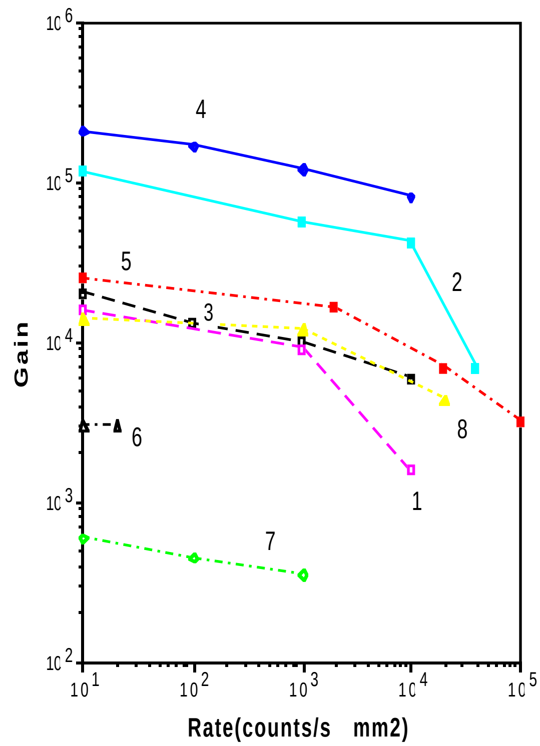

Fig 3. Maximum achievable gain (curves 1-7) as a function of x-ray flux in the presence of alphas for: 1) diamond-coated MSGC with 1 mm pitch , 2) MSGC (1) with GEM, 3) diamond coated MSGC with 0.2 mm pitch (from ref. [15]), 4) MSGC (2) with GEM, 5) PPAC with 3 mm gap, 6) thin gap (0.6 mm) PPAC, 7) CAT, 8) space-charge-limited gain variation for the MWPC in the presence of alphas at counting rate < 100Hz per 1cm of wire (our measurements).

Fig.3 shows the results under identical x-ray irradiatiing conditions to those in Fig.2, but with the addition of a collimated beam of alpha particles at a few kHz per few mm^2. In this case for the "PPAC"-type of detectors (PPAC, thin gap PPAC and CAT), an additional drop on 1-2 orders of magnitude (depending on the energy deposit in the drift gap) was observed. In this environment, the highest gains were achieved with the MSGC combined with a preamplification structure [6]. As an independent confirmation, we also plot in Fig.2, data from the Sauli group [15].

Finally, it is interesting to note that we found that the dependence of gain variation with rate of x-photons for the MWPC remains almost constant if the rate of the alpha particles was < 100Hz. Therefore the MWPC still remains attractive for many applications.

4. Discussion

We discovered that the maximum achievable gain in ALL the gaseous detectors tested drops dramatically, in some cases inversely proportional, with count rate. Further, in the presence of alpha particles, typical of the backgrounds in high-energy experiments, additional gain drops of 1-2 orders of magnitudes may appear. These measurements permit clear recommendations for choosing the optimum detector for particular experimental conditions. For example, for measurements of strong x-ray radiation (synchrotron radiation) MSGC+GEM, MICROMEGAS, and thin-gap PPAC's will be ideal candidates. However in the presence of alphas a good choice would be the MSGC with a preamplification structure, or even a conventional or thin-gap MWPC if their spatial resolution can satisfy the user's requirements. The MWPC can operate at high gains(A) in the presence of alphas as its total charge is not the critical parameter for corona-type breakdown, only its gain, which must remain below $A*g = 1$, where g is a probability of secondary processes. Of course, MICROMEGAS, CAT, thin gap PPAC still can operate at relatively high gains in the presence of alphas, but in this case the drift space should be reduced to 1 mm or less to limit the primary charge.

It is interesting to note that rate-limiting breakdowns in most of high rate detector do not occur through any of the three standard breakdown mechanisms invoked at low rates (streamers or two types of feedback loops)[16]. For example, in "PPAC"- types detectors (PPAC, MICROMEGAS, thin gap PPAC) high-incident-flux breakdowns occur through a memory effect: that is, the discharge gap somehow remembers the previous avalanche (for time intervals often much longer than the removal time of the ions!) and this lowers the breakdown limit. We call this new breakdown mechanism an accumulative breakdown, which may be associated with several phenomena. The most important of these is the ejection of jets of electrons by ion bombardment of exposed cathode surfaces, which can continue for minutes beyond the actual bombardment. Another is associated with the accumulation of excited atoms in the avalanche region, which may reach a critical concentration and provoke discharges. This latter phenomena was observed in pure noble gases [17] and there is speculation that this may be responsible for streamer formation in mixtures of gases also [18]. The results of a detailed study of this type of breakdown are given in Ref.19.

Conclusion

The highest achievable gain for x-rays (and presumably for minimum ionizing particles) are achievable in MSGC+GEM , MICROMEGAS and thin gap PPAC's. However, in the presence of heavy ionizing particles, MSGC+GEM can offer higher gains. In some high-rate measurements, the standard or thin-gap MWPC can be also be used if its spatial resolution satisfies requirements.

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