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Rate and gain limitations of MSGCs and MGCs combined with GEM and other preamplification structures

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Abstract

We have studied the rate and gain limits of diamond-coated Microstrip Gas Counters (MSGCs) and Micro-Gap Counters (MGCs) when combined with various preamplification structures: Gas Electron Multiplier (GEM), Parallel-Plate Avalanche Chamber (PPAC) or a MICROMEGAS-type structure. Measurements were done both with X-rays and alpha particles with various detector geometries and in different gas mixtures at pressures from 0.05 to 10 atm.

The results obtained varied significantly with detector design, gas mixture and pressure, but some general features can be identified. We found that in *all* cases, bare MSGCs, MGCs, PPACs and MICROMEGAS, the maximum achievable gain drops with rate. The addition of preamplification structures significantly increases the gain of MSGCs and MGCs, but this gain is still rate dependent.

There would seem to be a general rate-dependant effect governing the usable gain of all these detectors. We speculate on possible mechanisms for this effect, and identify a safe, spark-free, operation zone for each system (detector + preamplification structure) in the rate-gain coordinate plane.

1. Introduction

In our previous paper [1], we investigated the gain and breakdown limits of MSGCs combined with the GEM [2] and other preamplification structures. The main question we tried to answer was why does the addition of the GEM preamplification structure permit MSGCs to operate at higher overall gains. The conclusion of these studies was that this is due to the additional diffusion which clouds of primary electrons experience when preamplified through the GEM structure. This lowers the charge-cloud density by a factor of ~ 10 and, as a consequence, allows higher total charges to be reached in the MSGC avalanche before streamers appear. From these studies it followed that other preamplification structures could perform equally well and, indeed, it was found that a PPAC + GEM combination gave excellent gain and energy resolution characteristics. These studies were done at low rates.

In this paper we extended our studies to high rates (10^4–10^7 counts/s mm^2) where a new

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phenomenon was observed to become important:- that the maximum achievable gains of *all* types of gaseous detectors tested drop with rate. This effect should be taken into account when designing, developing and exploiting high-rate gaseous detectors.

2. Experimental setup

The experimental setup was essentially the same as in previous studies [1]. Inside the gas pressure vessel, various "detectors" (MSGC or MGC) could be installed with various "preamplification structures" (GEM, PPAC or MICROMEGAS-type [3]), 4–10 mm above them. The MSGCs tested in this work, were obtained from IMT (Switzerland). They were diamond coated ($\sim 10^{15}\,\Omega$/square) and had pitches of 0.2 and 1 mm and anodes strips of width 10 μm. The MGCs were obtained from INFN (Pisa) and Delft University and had 0.1 and 0.2 mm pitches. Both type of detectors were baked in vacuum for 24 h at a temperature $\sim 75°$C before use.

The GEM preamplification structure, obtained from CERN, had a thickness of 50 μm, hole diameters of 80 μm and a hole pitch of 200 μm. The PPAC preamplification structure had a gap adjusted to be either 1 or 3 mm [1]. The MICROMEGAS-type preamplification structure was designed from two round frames, 5 cm diameter each, with 3 μm thick, 50% optically transparent mesh stretched and glued to each. Fiber-type spacers with a pitch ~ 3 mm maintain mesh separation. The diameters of the fiber spacers were, depending on the particular design, 0.1, 0.2 and 0.4 mm.

Measurements were done in various Ar-, Xe-, Ne- and He-based mixtures at pressures from 0.05 to 10 atm. As sources of ionization, both X rays (6 or 17.5 keV lines from a generator) and alphas (~ 5.5 MeV) were used. The gas gain of the "detectors" was determined from the ratio of the current in multiplication mode to the value of the saturated current in ionization mode (see [3] for more details). A picoammeter, Keithley model 487, was used in these measurements. At very high gains, however, the picoammeter was not used due to concerns about breakdown-induced damage. In these cases, injecting a known charge to the detector preamplifiers through a capacitor performed a standard calibration.

The intensity of the X-ray beam from the gun was also independently calibrated using a separate single-wire counter (see Ref. [4]), working either in counting or current mode (depending on the flux).

3. Results

Typical dependencies of maximum achievable gain vs. rate for MSGCs and MGCs are presented in Fig. 1. Here, the maximum achievable gain was defined as the gain at which frequent (one per few minutes) breakdowns appeared. As breakdown rates are highly variable this is a somewhat imprecise quantity, with uncertainties in maximum achievable gain of up to a factor of two possible. Thus the lines in Fig. 1 should be considered as indicative of trends only. However, in spite of these uncertainties, one can clearly see that the maximum achievable gain both for MSGCs and MGCs drop rapidly with rate. Also presented are the data for MSGCs and MGCs combined with GEM and PPAC preamplification structures (referred to as MSGC + GEM, or MGC + GEM, and MSGC + PPAC, respectively.) In these measurements the GEM or PPACs were kept at constant voltage and the anode voltage on the MSGGC or MGC were steadily increased until breakdowns appeared. Further increases in gain were achievable by applying more voltage to the GEM or PPAC and to the transfer region between sections. The conclusions were always the same however: the maximum achievable gain *always* drops with rate.

Qualitatively, the same results were achieved with MICROMEGAS-type preamplification structure. However, compared to the PPAC, the maximum achievable gains in this configuration were a few times lower and the energy resolution even at low rates was much worse (30–40% FWHM for 6 keV, compared with 15–17% for the PPAC with a 3 mm gap [1]). Note that the results presented in Fig. 1, were all obtained in a P10 gas mixture. However, the same results qualitatively (drop in maximum achievable gains with rate) were

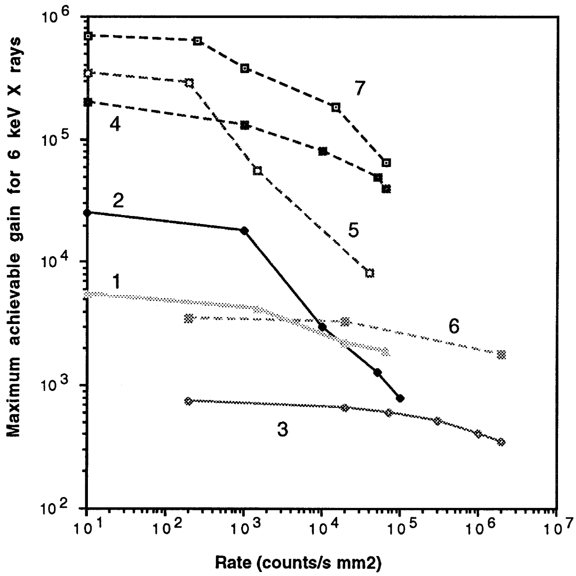

Fig. 1. The maximum achievable gain as function of rate (6 keV X-rays) for an MSGC with 0.2 mm pitch (1), an MSGC with 1 mm pitch (2), an MGC with 0.2 mm pitch (3), an MSGC (type 1) + Gem (4), an MSGC (type 2) + GEM (5), an MGC (type 3) + GEM(6), and an MSGC (type 2) + a PPAC with a 3 mm gap (7). The distance between the preamplification structures and the detectors was $\sim$ 1 cm and the applied voltage in the transfer gap was $\sim$ 1 kV. The diameter of the X-ray beam was $\sim$ 5 mm. In case of GEM, the results were corrected for gain variations due to GEM charging. The fill gas was *P*10 at 1.05 atm for all cases.

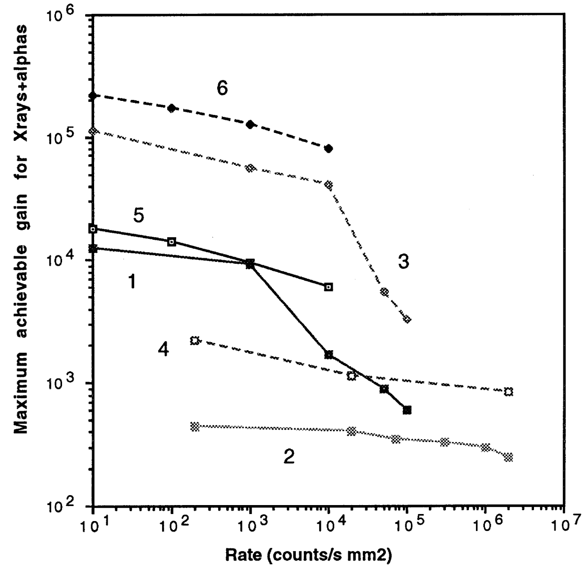

Fig. 2. The maximum achievable gain as a function of rate (6 keV X-rays + a few kHz from alphas) for the MSGC with 1 mm pitch (1), the MGC with 0.2 mm pitch (2), and the MSGC + GEM and MGC + GEM combinations, (3) and (4). The distance between the preamplification structures and the detectors was $\sim$ 1 cm and the applied voltage in the transfer gap was $\sim$ 1 kV. The diameter of the X-ray beam was $\sim$ 5 mm. The fill gas was *P*10 at 1.05 atm for all cases (1–4). Curves (5) and (6) represent the maximum achievable gain for the MSGC with 0.2 mm pitch and the MSGC + GEM combination measured in work [2] in an Ar/DME mixture at 1.05 atm.

obtained in all tested gas mixtures. There were of course some additional features. For example, the maximum achievable gains in Ar- and Xe-based mixtures always dropped with pressure as opposed to some He- and Ne-based mixtures where the gain sometimes passed through a maximum at some particular pressure. Nevertheless, under any fixed conditions, the maximum achievable gain dropped with rate. The other important feature was that, as a rule, the maximum achievable gain also depended on the X-ray beam diameter and decreased as the beam size increased.

Fig. 2 shows results of measurements of the maximum achievable gains for MSGCs and MGCs, and the MSGC + GEM and MGC + GEM combinations, when, in addition to the X-rays, a collimated (perpendicular to the detector surface) beam of alpha particles was introduced (at a few kHz per a few mm^2 area). One can see that in the presence of alphas all the maximum achievable gains exhibit additional drops. This behavior remained qualitatively the same in all gases tested. Fig. 2 also shows the results of similar measurements performed earlier, as detailed in Ref. [2].

After observing a systematic drop of maximum achievable gains with rate in the detectors described above, the rate behaviors for bare PPACs and MICROMEGAS were measured [5]. Some of these results are presented in Fig. 3. One can see that even for these detectors, the maximum achievable gain drops with rate. We should note that our "home-made" MICROMEGAS had, in general, a faster gain drop with rate than the commercially available MICROMEGAS [6]. We attribute this difference to the poorer quality of our MICROMEGAS and to avoid any confusion we present, in

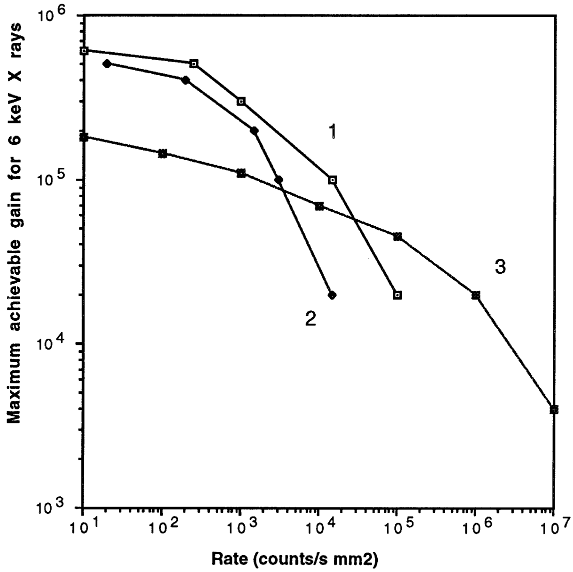

Fig. 3. The maximum achievable gain as function of rate (6 keV X-rays) for the 3 mm-gap PPAC (1,2), and for MICROMEGAS (3) (from Ref. [6]). Curve (1) corresponds to a beam diameter of 2 mm and curve (2), to a beam diameter of 20 mm. The gas mixture was Ar + 5% isobutane at 1 atm.

Fig. 3, only the rate behavior for a commercial MICROMEGAS obtained from Ref. [7]. One should note that in the presence of alphas, a more realistic environment in many experiments, the values of maximum achievable gain plotted here were further reduced by 1–2 orders of magnitude [5] (depending on the charge density and total charge deposited in the drift region) and this could be a serious limitation in some applications.

One immediate conclusion from all these measurements is that, for safety, one should always operate at gains much below those depicted in Figs. 1–3.

4. Discussion

The observation that for all the detectors tested the maximum achievable gain drops with rate implies a general rate-dependant effect governing the useable gain. One possible explanation could be a "defects-activation effect" [8–10].

As an example, consider the MICROMEGAS detector. From Fig. 3 one can see that in MICROMEGAS, even at rates of 10^2–10^3 Hz/mm^2, the maximum achievable gain is already starting to drop. It is known that the ion-removal time from the MICROMEGAS gap is ~ 100 ns, so at these rates the positive ions for each particular avalanche are completely removed before the next avalanche starts to develop. Each avalanche therefore develops completely independently of the previous one.

Now there are three known classical mechanisms of breakdowns [11]:

(1) through streamers development,
(2) by a photon feedback loop,
(3) through an ion feedback loop.

Streamers develop at some critical total charge density in the avalanche $AN_0 = Q$ crit, where A is the gas gain and N_0 is the number of primary electrons created by the X-rays in the gas (~ 220 for 6 keV). Since the maximum achievable gain for MICROMEGAS is observed to drop even at moderate rates, the total charge in the avalanche AN_0 correspondingly reduces and therefore streamers will not form unless there are avalanches overlapping in time and space. However, at rates $\sim 10^2$–10^3 Hz the probability of such overlapping avalanches is very small. This implies that we should look to mechanisms 2 or 3, or possibly a new mechanism, for breakdowns in MICROMEGAS. Indeed, photon feedback-induced breakdown was already observed in MICROMEGAS-type detectors in some gases, for example Ar + 20% CO_2 [5]. The conditions for breakdowns through mechanisms 2 and 3 are $AG_{ph} = 1$ or $AG_{ion} = 1$ [11], where G_{ph} and G_{ion} are the probabilities for photons or ions to extract a secondary electron from the cathode of the detector. Since A is observed to drop, then for these mechanisms to take effect there must be a corresponding increase in the coefficients G_{ph} or G_{ion}.

We should note that an increase of the coefficient G_{ph} under intense photon bombardment of the cathode was observed in earlier works [12,13]. Similarly, an increase of G_{ion} under intense ion bombardment was observed in Refs. [9,10]. Therefore, these can be considered as established experimentally. One possible explanation for these phenomena is that intense ion fluxes change the surface layer composition and also charge dielectric inclusions on metallic surfaces. The charging of these inclusions causes electron emission (Malter-type effect) and may also be accompanied by explosive field emission [14]. This effect is strongly enhanced when the surface has defects such as points or inclusion. Such jets of electrons were observed experimentally in the case of PPAC detectors [10] and in MICROMEGAS-type detectors [5]. These jets can also trigger breakdown. Therefore, we speculate that breakdowns in the MICROMEGAS detector and its rate behavior (as presented in Fig. 3), may be attributed to this type of phenomena. Note, however, that in MICROMEGAS, the mean-free-path of UV photons produced in the avalanche is larger than the multiplication gap. Therefore, we cannot rule out new, unknown, mechanisms or combinations of those covered here (such as streamers created by jets, plus a feedback mechanism).

The same rate-dependent mechanisms 2, 3 may also be assumed for the case of the MSGC (see Ref. [9] for more details), probably the MGC, and, as mentioned above the PPAC, at least at intermediate rates (10^3–10^4 Hz/mm^2). At higher rates, however the PPAC may experience avalanche overlapping [15], due to the slow removal time of the positive ions from the gap, and this leads to the much faster drop of maximum achievable gain with rate observed experimentally (see curves 1 and 2 in Fig. 3).

5. Conclusions

In all detectors tested (MSGC, MGC, PPAC, MICROMEGAS) the maximum achievable gain always drops with rate. The addition of preamplification structures improves the gain at any given rate, but the overall tendency remains the same. This implies a general mechanism governing the maximum achievable gain. One possible explanation could be a "defects activation" effect in which electrons are emitted from defects, such as points and inclusions, by intense ion bombardment, promoting feedback loops and subsequent breakdowns. This effect may additionally complicate designing and exploiting some types of gaseous detector at high rates.

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