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Operating range of a gas electron multiplier for portal imaging

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Abstract

At the Karolinska Institute in Stockholm, Sweden a new detector for portal imaging is under development, which could greatly improve the alignment of the radiation beam with respect to the tumor during radiation treatment. The detector is based on solid converters combined with gas electron multipliers (GEMs) as an amplification structure. The detector has a large area and will be operated in a very high rate environment in the presence of heavy ionizing particles. As was discovered recently high rates and alpha particles could cause discharges in GEM and discharge propagation from GEM to GEM and to the readout electronics. Since reliability is one of the main requirements for the portal imaging device, we performed systematic studies to find a safe operating range of the device, free from typical high rate problems, such as discharges. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Portal imaging device; Gas electron multiplier; Discharge study

1. Introduction

At the Karolinska Institute in Stockholm, Sweden, a new detector for portal imaging is under development which could greatly improve the alignment of the radiation beam with respect to the tumor during radiation treatment. It is described in detail in Ref. [1]. It will be based on gas and solid photon–electron converters combined with gas electron multipliers (GEMs) [2] and for this reason has been named Gaseous Electron multiplier Portal Imaging Device (GEPID) [1]. The detector will have a large area (40 cm × 40 cm) and will be operated in a very high rate environment (⩽5 Gy/min) in the presence of neutrons. The neutrons originate from treatment machines operating at electron beam energies up to 50 MeV.

At high rate intensities a typical problem is that a destructive discharge may occur at relatively low gain, and more than that, it could even propagate through the gas volume to another GEM (if two or more GEMs are working in tandem) or to the electronic readout board. Since the main requirement of an EPID (electronic portal imaging device) is the reliability, a systematic study of these phenomena was started recently in order to find conditions for a safe operation free from these problems [3–5]. The fact that the GEM is now used in many large experiments at CERN and elsewhere makes these studies more interesting, because the

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problem with discharges applies to everyone using the GEM.

The overall aim of the work was to investigate the possibility of using the GEM detector in EPIDs and in other high rate applications.

2. Setup

For the experiments a prototype was built and extensively tested. In the prototype gas chamber one or two GEMs were placed together with a drift electrode and a readout board. The GEMs used in the experiments were obtained from CERN and had an active area of $10\,cm \times 10\,cm$. The irradiation source was either an X-ray gun allowing up to 60 kV and 60 mA or an alpha source (^{241}Am) placed inside the chamber. The chamber was continuously flushed through with a gas at 1 atm pressure and measurements were made with Ar + 20% CO_2 and Ar + 5% isobutane. The GEM closest to the drift electrode was called GEM 1 and the GEM closest to the collector was called GEM 2 (see Fig. 1).

To be able to monitor the currents during breakdowns on the drift, the readout and the GEM electrodes, three double channel storage oscilloscopes were used. To protect the oscilloscopes, the voltage was usually divided 100 times by capacitive dividers. To understand the influence of these dividers on the breakdown signals they were varied several times.

The GEM electrodes and the drift electrode were powered through high-value resistors by individual power supplies, able to work with some inverse current. This made it possible to change all the electric fields in the detector independently. The resistors limited the currents in the GEM during breakdowns and made it possible for a GEM to withstand more than a hundred breakdowns before it stopped working.

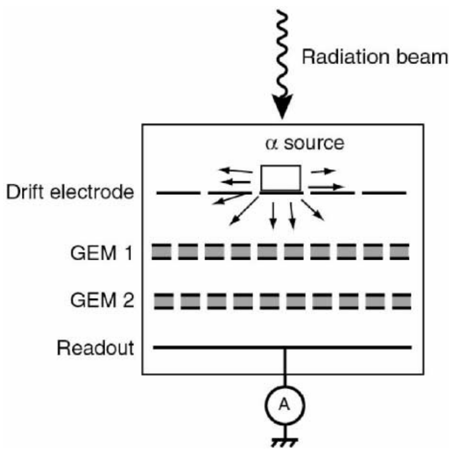

Fig. 1. Schematic drawing of the prototype used for the measurements with X-rays. The drift and the GEM electrodes were each connected to a power supply through large protective resistors.

3. Results

The work was started by performing a general study of the GEM to see how it would perform in a high rate environment [6,7]. Then followed a study of the problem of discharges in GEMs and the safe operating range of the GEM was determined.

To fully understand the response of the electrodes during a breakdown, pickup signals were thoroughly studied (Fig. 2). It was seen that when

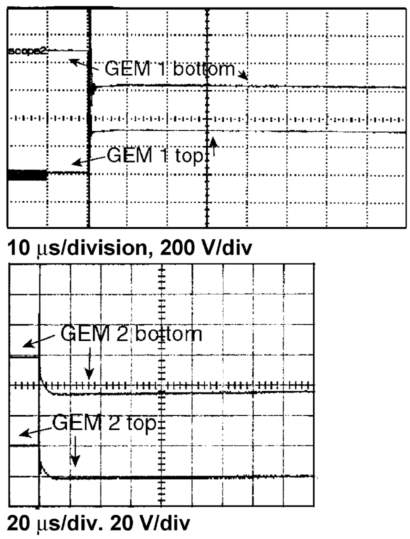

Fig. 2. Example of typical signals from all electrodes in the detector when there is a breakdown in GEM 1. On GEM 1 breakdown signals are seen and on GEM 2 pickup signals are seen. The pickup signals consist of one square part and one rounded part, due to ion movement.

there is a breakdown in one GEM, on the other GEM the signal consists of both a pickup part and a rounded part caused by ion movement. When square generator test pulses were applied to one GEM the pickup signals on the other GEM showed no rounded part.

3.1. Discharge study: with X-rays

For the measurements with X-rays two GEMs in tandem were mostly used. A discharge in one of these GEMs can spread to the other GEM, so that the discharges occur simultaneously in both GEMs. Measurements were made of the time delay between the breakdowns in GEM 1 and GEM 2 (see Fig. 1) and no time delay was found with the accuracy of $\sim 10\,\mathrm{ns}$. Also breakdown propagation was found to be independent of the electric field strength between the GEMs. Propagation occurred many times for reversed field strength between the GEMs, i.e. a larger negative potential on GEM 2 top than on GEM 1 bottom.

Due to the risk of destruction of electronics connected to the readout, the worst situation for the detector could be discharge propagation from a GEM through the gas to the readout board. This type of propagation was found to occur only for electric fields (between GEM 2 and the collector) above a threshold of approximately 10 kV/cm.

3.2. Discharge study: with alpha particles

The heavy ionizing particles that may be produced by neutrons originating from the treatment machine could trigger discharges in the detector even at low rates. To simulate the contribution of neutrons, experiments were made with one or two GEMs and an ^{241}Am source. With alpha particles the maximum achievable gain of the GEM was less than with X-rays.

3.2.1. Pre-propagation changes

In measurements made with X-rays the discharge to the readout board propagates only for fields above a critical value ($>10\,\mathrm{kV/cm}$), see above. In the presence of alpha particles the picture was different. With the increase of the field between the GEM and the readout board a gradual increase of the signal on the readout board was observed, as well as an increase of the asymmetry in the signals from GEM bottom and GEM top. We called them "pre-propagation changes". Finally, at a critical electric field ($>2\,\mathrm{kV/cm}$) full propagation occurs [3].

The "symmetry" of a breakdown in GEM 2 depends on the voltage drop across GEM 1. When GEM 1 works at some gain breakdowns in GEM 2 become asymmetric, indicating that some charge sharing occurs between the two GEMs.

3.2.2. Delayed breakdown

To model a large size GEM the electrodes of the GEM were each coupled via a 5 nF capacitor to ground. A new phenomenon was seen. Sometimes the discharge in the GEM was, after a time delay, followed by discharge propagation down to the readout board (see Fig. 3). The length of this time delay was very sporadic and varied from a fraction of a μs up to 20 μs. From Fig. 4 one can see that in the time interval between two breakdowns there is some current flowing between the GEM and the readout board. The value of this current increases with time. Measurements show that at this

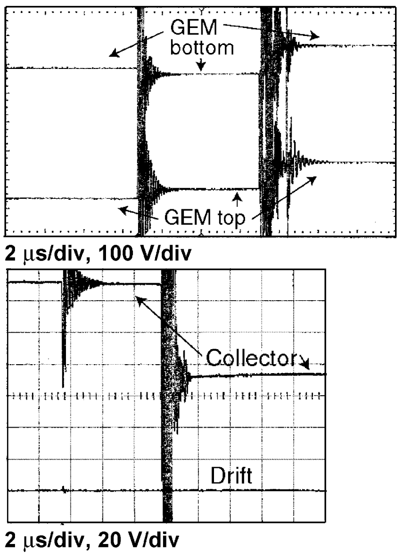

Fig. 3. The discharge in the GEM is followed by a discharge propagation to the readout board after a time delay of a few μs.

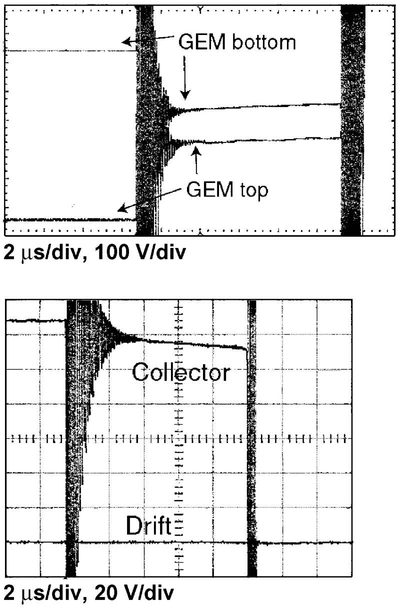

Fig. 4. Between the two breakdowns a slope is seen. It is positive on both GEM electrodes and negative on the collector.

moment electrons, depending on applied voltage, experience gas gains between 100 and 1000.

Tests were made to connect a 5 nF capacitor to only one of the GEM's electrodes (instead of to both). When the capacitor was connected to the top electrode of the GEM, the delayed breakdown appeared at less applied voltage between the GEM and the readout board.

3.3. Discharge study: with X-rays and alpha particles

The results of the measurements with both X-rays and alpha particles did not differ significantly from the results achieved with alpha particles only. The alpha particles dominate the discharge situation.

4. Discussion

Since no time delay was found for the GEM to GEM propagation and since it was independent of the electric field between the GEMs it was concluded to be due to photomechanism, i.e. photons propagate the discharge. The hypothesis is that ultraviolet photons created in the breakdown in a GEM ionize gas molecules in the detector and the created photoelectrons are injected into the other GEM and cause a breakdown. Possible ways to suppress propagation of discharges between GEMs was found to be an increased distance between GEMs or a reduction of the gain in the "receiving" GEM.

Ways to suppress breakdown propagation down to the readout could be to increase the distance between the GEM and readout and to keep the electric field below the critical value of $\sim 10\,\mathrm{kV/cm}$.

4.1. Delayed breakdown

One possible explanation to breakdowns with delay could be the so-called "cathode excitation effect". It is known that after intense ion bombardment the surface property of the cathode may dramatically change. Its work function, i.e. the energy required for extracting electrons, reduces and the cathode starts to spontaneously emit jets of electrons. Both these phenomena were observed experimentally by several groups and it got the unofficial name "cathode excitation" (see Ref. [8] and references therein). Macroscopically, the "cathode excitation effect" manifests itself in sudden electrical "weakness" of the breakdown gap. Usually, one cannot immediately apply the same voltage to the detector as before the breakdown, but one has to wait for some time. This phenomenon depends very much on the cathode material and the gas. In some gases (for example, in mixtures with isobutane) it may last for minutes or even hours.

There is no doubt that after the spark in the GEM the cathode region close to the spark gets "excited". The ions from alpha particles that are collecting during a few μs after the initial breakdown, will then bombard the already "excited" surface. Due to the lowering of the work function the condition for the efficient feedback loop $A\gamma_+ \approx 1$ (A is the gas gain and γ_+ is the probability for positive ions to extract an electron from the cathode) can be satisfied at very low gas gain in the region between the GEM and the collector.

Experimentally, it appears as a slow current growth. Breakdown then appears due to ion feedback or, more likely, by a combination of the ion feedback with the jet emission.

5. Conclusion

The first tests of the GEM have successfully been finished with promising results. We concluded that the GEM could successfully be used in EPIDs and for other high rate applications.

The studies show that GEMs can operate at extremely high rates ($>10^6\,\mathrm{Hz/mm^2}$) with no sign of degradation and stability loss due to radiation damage. However, it was discovered that the maximum achievable gain for all planar gaseous detectors drops with the beam intensity. It seems, however, like the maximum achievable gains of the GEM at high rates will be sufficient for the portal imaging device we are developing and that the detector will not suffer from problems with discharges. In real clinical operation the detector can operate safely with a gain of 10^2 in the GEM closest to the collector.

Results of these studies allowed us to build an optimized design of an EPID, which will soon be tested in a real clinical beam treatment set up at the Karolinska Hospital.

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