Aging tests with GEM-MSGCs

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The Inner Tracker of the HERA-B experiment at the Deutsches Elektronen-Synchrotron (DESY) is a position-sensitive detector which has to cope with a particle flux up to $2 \cdot 10^4$ MIPs $\mathrm{mm}^{-2}\mathrm{s}^{-1}$ and a radiation dose up to 1 Mrad/year (10 kGy/year). The system consists of Microstrip-Gas-Chambers (MSGC) using a Gas Electron Multiplier (GEM) as preamplifier structure in the gas volume. During the R&D phase, long-term aging measurements with X-rays were performed to study which electrode material and counting gas do not lead to aging of the detector over long running periods.

1. Introduction

HERA-B is a magnetic forward spectrometer and the Inner Tracker is a position-sensitive detector which covers the region 6 cm $\leq R_\perp \leq$ 30 cm around the beam pipe [1]. In this region the detector has to cope with a particle flux up to $2 \cdot 10^4$ MIPs/mm^2s. Due to the high integrated particle flux the detector will be exposed to a radiation dose up to 1 Mrad/year (10 kGy/year). In view of these two requirements, the question of radiation hardness and long-term stability is of special importance.
The time scale of the accelerated aging measurements described here was set by the accumulated charge. Using the GEM-MSGC technology the accumulated charge on the anode strip amounts to 5 mC/cm per year when the detector is operated with a total gain of 4000. The detectors were irradiated with a X-ray tube (copper anode) with a particle flux up to $2 \cdot 10^4$ γ/mm^2s. Due to photon conversion the primary ionization is $\sim$10 times larger than from a minimum ionizing particle (MIP). Consequently, the acceleration factor was as high as 10 when this charge density in the electron avalanche is taken into account (for more details see [2]).

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2. GEM-MSGC and electrode material

The GEM-MSGC detector comprises the microstrip structure, the GEM foil, and the drift electrode (see Figure 1). Two frames ensure the mechanical stability and define the drift gap and the transfer gap to 3 mm each. The detector is based on a two-step gas amplification. The primary ionization created by an ionizing particle passing the drift gap is amplified in a first amplification step in the electric field in the holes of the GEM foil. The second amplification step takes place in the field near the anode strips of the microstrip structure. The first amplification step allows to reduce the field at the anodes such that the probability of discharges induced by heavily ionizing particles is lowered by several orders of magnitude relative to a MSGC without GEM foil.

2.1. Microstrip structure

The microstrip structure is based on a 300 μm thick, alkali-free glass substrate (AF45) from DESAG [3] with a *diamond-like* coating applied by SURMET [4]. This coating has a surface resistivity of $2 \cdot 10^{14}$ Ω/square. The electrode structure itself has a pitch of 300 μm, the anode strips have a width of 10 μm and the gap between anode and cathode strips is 60 μm. The microstrip structure was produced by IMT [5] using a lift-off process. For the aging tests the structure was made either of aluminum or gold. Aluminum is preferable for a lithographic process and is robust with respect to cleaning procedures or discharges. Gold

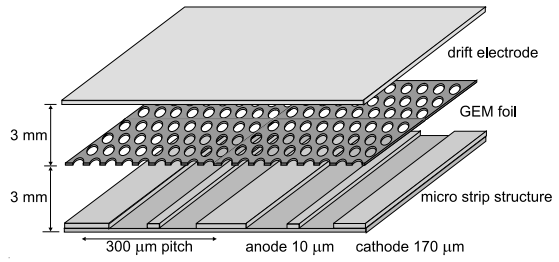

Figure 1. Cross section of a GEM-MSGC detector used for the aging tests.

is much more sensitive. Both materials have a low resistance ($\sim$10 kΩ/m). This is important because the Inner Tracker has to deliver fast signals for the trigger even if the strips for the full-size detectors are up to 25 cm long. Consequently, chromium or nickel can not be used.

2.2. Test detectors

The detectors for the aging tests had a size of (10×10) cm^2 and the frames were made of G10 or PEEK. The GEM foils were produced at the CERN Workshop [6] using a wet etching technique. The GEM foils were made out of 50 μm thick polyimide (Kapton) foils coated with a 15 μm copper layer on each side. In a second etching step, the thickness of the copper layers was reduced to about 7 μm. The drift electrode consists of a 100 μm thick Kapton foil covered with 17 μm copper. The detectors were glued with EPO-TEK H72 [7] which has no influence on the detector performance with respect to aging [8].
The detectors were powered with independent high voltage supplies for the drift voltage and the cathode voltage. Both GEM voltages were generated from the drift voltage and could be adjusted with a voltage divider. Each high voltage channel was equipped with a current meter with nA accuracy. The signals were read out with the charge sensitive preamplifier VV50 [9], which was developed at the University Heidelberg.
The detectors were irradiated with a particle flux up to $2 \cdot 10^4$ γ/mm^{2}s over a surface of 100 mm^2. In the test with Ar/CO_2 described in section 4.1, the irradiated area was 350 mm^2.

3. Gas system and counting gas

3.1. Gas system

A very clean gas system was used for the gas supply. All tubes, valves, flow meters, tube fittings and pressure regulators were made of stainless steel. All sealing rings were made of Kalrez. The exhaust of the gas system consisted of 10 m tube without a bubbler. Furthermore, several bypass devices allowed to add α-particles as well as 0.3 % water to the counting gas. The gas flow was 10 ml/min, this corresponds to approximately 10 detector volumes per hour.

3.2. Counting gas

The aging tests were done with two different counting gases, Ar/DME or Ar/CO_2.
The mixture Ar/DME (50/50) has a high primary ionization and a small Lorentz angle. As DME is a good quencher, fewer problems with discharges were expected. It is radiation-hard and, even though it is a hydrocarbon, there were promising results reported by other groups who did not observe aging effects up to large values of accumulated charge (see e.g. [10]). However, as the Ar/DME mixture is flammable, a lot of safety requirements have to be taken into account. Due to high costs for cleaning procedures, DME is not delivered with a guaranteed purity. For the use in a large experiment like HERA-B every bottle needs to be tested to assure that the detector system is not polluted during operation. In addition, DME is a polar molecule and is absorbed by the hygroscopic Kapton. This reduces the mechanical tension of the GEM foil.
The mixture Ar/CO_2 (70/30) has the advantage that it is non-flammable and will not show any polymerization effects. But this gas mixture has the main disadvantage of reduced high voltage stability. In addition, due to the lower primary ionization the high voltage has to be increased to receive the same signal size. Consequently, discharges will have a larger energy. The gas mixture has also a larger diffusion than Ar/DME.

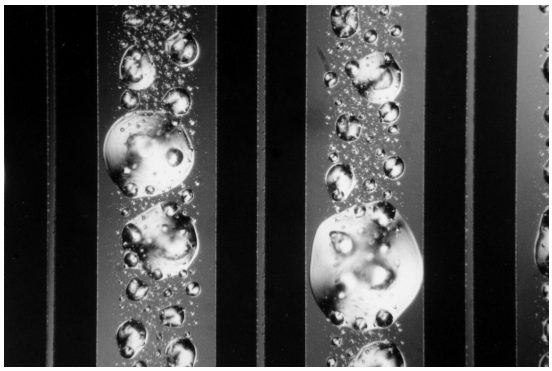

Figure 2. Aging of a microstrip structure made of aluminum. The photo shows a detector which was operated with Ar/CO_2 (70/30) up to an accumulated charge of 2.7 mC/cm. In the irradiated area the cathode strips showed small and big bubbles.

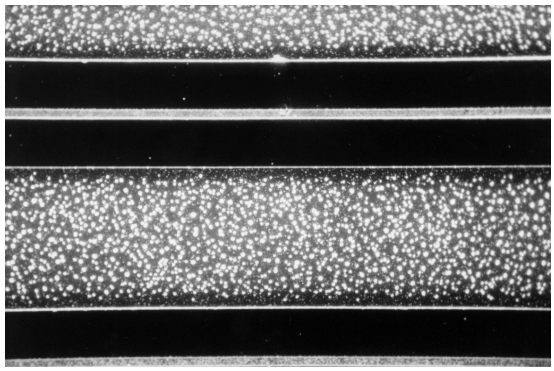

Figure 3. Aging of a microstrip structure made of aluminum. The photo shows a detector which was operated with Ar/DME (50/50). Already after an accumulated charge of less than 1 mC/cm, the cathode strips were covered with small craters.

3.3. Water admixture

To compensate the reduced high voltage stability and to avoid discharges in the GEM foil even during the operation with Ar/DME, we added a water admixture of 0.3 % to the counting gas. Consequently, there were fewer discharges in the GEM foil and at the edges of insulators, e.g. at the frames or the edges of glues, but the water admixture led to massive anode aging (see section 4.2).

4. Results of aging tests

4.1. Electrode material

Aluminum and gold were tested as electrode material for the microstrip structure. For aluminum the pulse height decreased to less than 50 % of the initial value, even for a total accumulated charge of much less than what is expected after one year of running at HERA-B. Aging was observed both with Ar/CO_2 (70/30) and Ar/DME (50/50) as counting gas. The cathode strips showed large and small bubbles after running with Ar/CO_2 (see Figure 2), while after the operation with Ar/DME the cathode strips were covered with small craters (see Figure 3).
No aging effects and no damage of the cathode strips were observed for MSGCs with a microstrip structure made of gold. In this case a 10% increase of the MSGC gain was observed after an accumulated charge of 16 mC/cm (see also section 4.3).

4.2. Anode aging

To exclude all possible influences of other materials a so-called "super clean" GEM-MSGC was built. The frames were made of glass instead of G10 or PEEK, and the drift electrode contained glass covered with gold instead of the copper-clad Kapton foil, which had been used for the regular test detectors. This "super clean" detector was operated with Ar/DME (50/50) either with or without an admixture of water. Simply by adding or excluding the water admixture to the counting gas, massive aging of the detector could be "switched" on or off. The diagram in Figure 4 shows the development of the pulse height as a function of the irradiation time and accumulated charge. In the case of a water admixture to the counting gas the pulse height decreased to 30 % of the initial value for an accumulated charge less than 3 mC/cm. Using dry Ar/DME the detector showed no aging over an accumulation period of 5 mC/cm. Even when the detector was op-

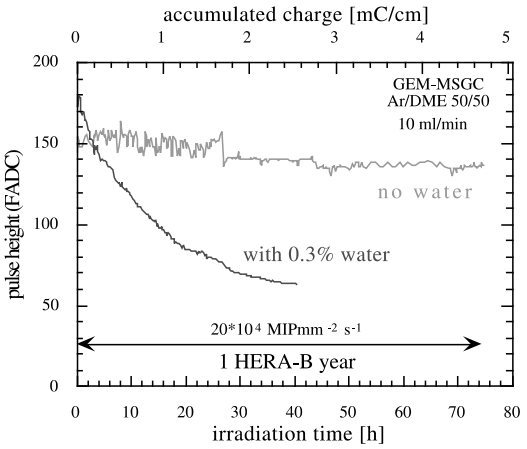

Figure 4. Aging of the GEM-MSGC detector due to a water admixture to the counting gas Ar/DME (50/50). The diagram shows the pulse height as a function of the irradiation time and the accumulated charge.

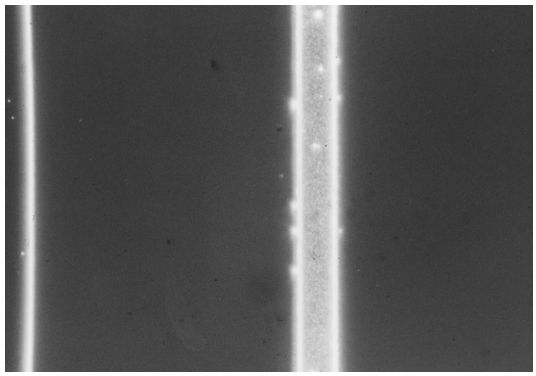

Figure 5. Anode aging of the GEM-MSGC detector due to a water admixture to the counting gas Ar/DME (50/50). The photo is taken with a special kind of illumination, under which an uneven surface brightens up. It shows the microstrip structure after 2.7 mC/cm. Near the left edge of the photo one can see the edge of the cathode strip and a dark - this means smooth - surface of the cathode. In the middle of the figure the bright coating of the anode strip is visible.

erated with Ar/CO_2, an admixture of water led to significant aging of the detector. The effect of adding the water is massive anode aging: It produces coating on the anode strips (see Figure 5). Another example of the influence of a water admixture to the counting gas is shown in Figure 6. In contrast to the "super-clean" detector described above, here the frames were made of G10. The detector was operated with Ar/DME including 0.3 % water. After an accumulated charge of 1.9 mC/cm the anode strips showed "whiskers-like" structures. These structures are not growing on the strips, but are running in the plane of the microstrip plate. It somewhat resembles "Lichtenberg figures" which are running in the *diamond-like* coating.

4.3. Change of MSGC gain

With the experience and knowledge gained from the results described so far, the test detectors could finally be operated with Ar/DME up to an accumulated charge of 16 mC/cm without any degradation of the detector performance. In this case even an increase of the MSGC gain of 10% was observed. As already described in section 2.1 these detectors had a *diamond-like* coating applied by SURMET. Unfortunately, the mechanical quality of the large-area coating was not satisfactory.
Therefore, the full-size detectors produced for HERA-B had a *diamond-like* coating applied by the Fraunhofer Institut [11]. The two coatings are very similar with respect to their chemical composition and electrical properties. However, with the Fraunhofer coating a quite different behavior was observed. Already after 5 mC/cm the MSGC gain increased by a factor of 2 and after 25 mC/cm even by a factor 3 to 5 [13].

4.4. Variations of GEM gain

Several effects of GEM gain variations were observed during the long-term tests. These variations mainly depend on the geometry of the GEM holes, especially the shape of the holes. In par-

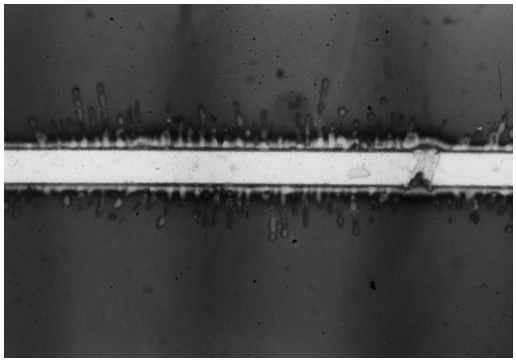

Figure 6. Anode aging of the GEM-MSGC detector due to a water admixture to the counting gas Ar/DME (50/50). The detector was operated up to an accumulated charge of 1.9 mC/cm. The photo shows the anode strip with "whisker-like" structures. Theses structures are in the plane of the microstrip plate.

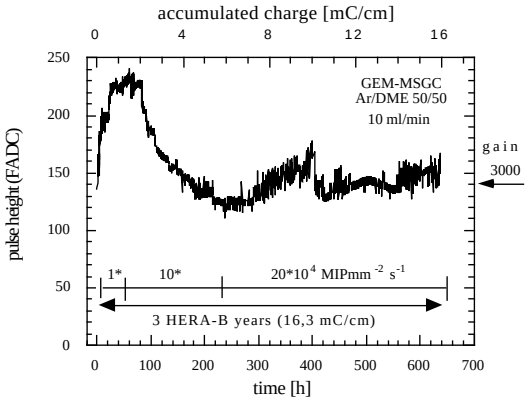

Figure 7. Variations of the GEM gain. The diagram shows the pulse height as a function of the irradiation time and the accumulated charge. All fluctuations of the pulse height are caused by variations of the GEM gain.

ticular, charging-up effects were enhanced when the holes had a "bi-conical" shape such that the surface of free Kapton is much larger compared to e.g. cylindrical holes. An example of a typical development of the GEM gain is shown in Figure 7. The diagram shows the pulse height as a function of the irradiation time. All fluctuations are caused by variations of the GEM gain. Within the first three days of operation the GEM gain increased by $\sim$60 %. After four additional days of operation the GEM gain decreased to the initial value. Within the next five days variations of $\pm$10% were observed.
The holes of the GEM foil used in this test had a pitch of 140 μm and a diameter of 120 μm for the copper and 50 μm for the Kapton, respectively.

4.5. Irradiated area and gas flow

Aging tests should be performed as close as possible to the expected and forseen conditions in the later experiment, especially with respect to the size of the irradiated area and the gas flow. To stress this point, we summarize the experience from the high-rate tests described herein and in [12], [13] as follows:

The R&D of the GEM-MSGC detectors for HERA-B can be subdivided into three major steps. Looking back, everything started with prototypes of (2×3) cm^2 size – at that time still MSGC detectors. The detectors were operated with Ar/DME (50/50) and irradiated on a surface of 10 mm^2. The gas flow was approximately 30 detector volumes per hour [12]. Then, the GEM-MSGC technology became available, and first prototypes with a size of (10×10) cm^2 were tested. The detectors were still operated with Ar/DME. The size of the irradiated surface was increased to 10^2 mm^2, the gas flow was lowered to 10 detector volumes per hour[2]. At last, the first full-size detectors with a size of (23×23) cm^2 were tested. The irradiated surface was once more increased to 10^4 mm^2, while the gas flow was reduced to the nominal value in the experiment of approximately 2 detector volumes per hour [13]. Each step was characterized by two changes: an increase of the irradiated area and a decrease of the exchange rate of the gas due to the larger volume of each new detector prototype. The tests which were performed at each level of development showed that one can only partly extrapo-

late from the results achieved before. This relates mainly to what materials and operation conditions should be used to avoid aging of the detector. Especially the problem of gas aging with DME turned out to be a recurrent problem even though it seemed to be solved during the step before. Finally, the counting gas had to be changed to Ar/CO_2, with which the detectors are still operated in the HERA-B experiment today.

5. Summary

The aging tests with GEM-MSGCs described here have shown that aluminum is not suitable for an operation with neither Ar/DME nor Ar/CO_2. A water admixture of 0.3 % to the counting gas reduces the number of discharges in the GEM holes and at the edges of insulators, but leads to massive aging of the detector in the case of Ar/DME and Ar/CO_2 as well.
Aging tests should be performed as close as possible to the real conditions. Consequently, the irradiated area of the detector should be as large as possible while the detector should be operated with a gas flow which is comparable to the final gas flow.

6. Acknowledgments

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