PROCEEDINGS OF SCIENCE

Irradiation and longevity test of Resistive Micromegas detectors

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A long-term irradiation and longevity test was conducted on two bulk-Micromegas detectors with screen-printed resistive strips, operated with Ar:CO_2 gas mixture at the CERN GIF++ facility between 2015 and 2018. The results have been presented at previous conferences and published. In that test the detectors have integrated a total charge of about 0.3 C/cm^2.

One of the detectors irradiated at GIF++ has subsequently undergone an ageing test with X-rays from Cu, this time with an Ar:CO_2:iC_4H_{10} mixture to study the effect of hydrocarbons like isobutane to the detector longevity. The resistive Micromegas under test has accumulated a total charge exceeding 1.5 C/cm^2, corresponding to about 15 years of equivalent irradiation of Muon detectors in the High Luminosity era of LHC and more than 5 at future hadron colliders like FCC-hh. The detector has been irradiated with an X-rays beam of variable intensity and the current, the gas temperature, humidity and pressure, and the environmental parameters have been monitored and registered all along the duration of the test. A second detector with identical construction and characteristics, operated at the same voltages and with the same gas but not irradiated, is used as reference chamber. Charge spectra with an ^{55}Fe source have been acquired at regular intervals for both detectors to monitor the evolution of the gain and energy resolution. The same test has been repeated by operating the detector with Ar:CO_2 gas mixture.

The paper describes the experimental setup and test operation, with focus on the main results and their interpretation. In particular we observe that the energy resolution stays largely unchanged, while the gain slowly reduces with irradiation, an effect interpreted as owed to charge up of the detector structure. No indication of performance degradation related to aging has been observed.

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1. Introduction

Resistive Micromegas [1] have been developed for the upgrade of the Muon Spectrometer of the ATLAS Experiment at LHC [2] leading to the successful construction of the largest MPGD-based system ever. Since then, many other MPGD exploiting the resistive protection schema have been developed and are finding application in HEP experiments.

The characterisation of the aging behaviour of gaseous detectors is crucial for application in large experiments with a long operation lifetime and high radiation background. A long-term test has been performed between 2015 and 2018 on two resistive bulk-Micromegas at the CERN Gamma Irradiation Facility (GIF++, 14 TBq Cs γ-source) with Ar:CO_2 93:7 gas mixture, as reported in [3].

The used mixture, however, is known not to be the best option to optimise the detector performance, but ensures on the other hand a safe operation against aging. The addition of stronger quenchers like hydrocarbons allows better operating conditions, in particular: higher gain at fixed voltage; anticipated turn-on curve resulting in lower operating voltage and reduced spark probability; larger stability plateau. An example is shown in figure 1 where the gain curve of the same detector operated with Ar:CO_2 90:10 and Ar:CO_2:iC_4H_{10} 88:10:2 is reported. The relevant effect boosting the detector gain is the Penning transfer [4].

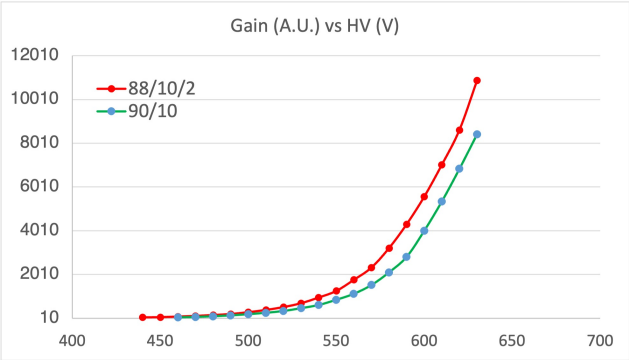

Figure 1: Amplification curve of the same resistive Micromegas operated with Ar:CO_2 90:10 and Ar:CO_2:iC_4H_{10} 88:10:2.

A good gas mixture candidate for operating resistive Micromegas has been identified in Ar:CO_2:iC_4H_{10} 93:5:2. The mixture is cheap (Ar-based), has a low global warming power and is not flammable. Moreover, the transport properties are very similar to Ar:CO_2 93:7, a gas that was extensively used during the development phase of resistive Micromegas. On the other hand the experience with wire chambers, very sensitive to the presence of hydrocarbons [5], calls for thoroughly longevity tests before coming to conclusion about resistive Micromegas. In that spirit we have started a longevity test campaign on such detector technology operated with Ar:CO_2:iC_4H_{10} 93:5:2. The first study, described in the following, consists in an accelerated test with X-rays.

2. Experimental setup and test procedure

The test has been carried out in the Gaseous Detector Development (GDD) laboratory at CERN of the RD51 Collaboration, on a detector named T8. It has an active area of 10x10 cm^2, an

amplification gap of 100 μm and a drift region of 5 mm. The resistive layer is made of strips printed on a 50 μm-thick Kapton substrate. The resistive strips, as well as the copper readout strips, have a widht of 300 μm and are spaced by 100 μm. A second Micromegas, named T2, built with the same design, material and construction technique as T8 has been used as reference detector. Both T2 and T8 have been built at the CERN MPT workshop.

During the test T8 was exposed to an intense X-ray radiation from Cu (8.04 keV K-α line) on a limited surface of 1 or 0.5 cm^2. The X-ray intensity can be changed by tuning the current of the X-ray generator. Figure 2 left shows the experimental setup.

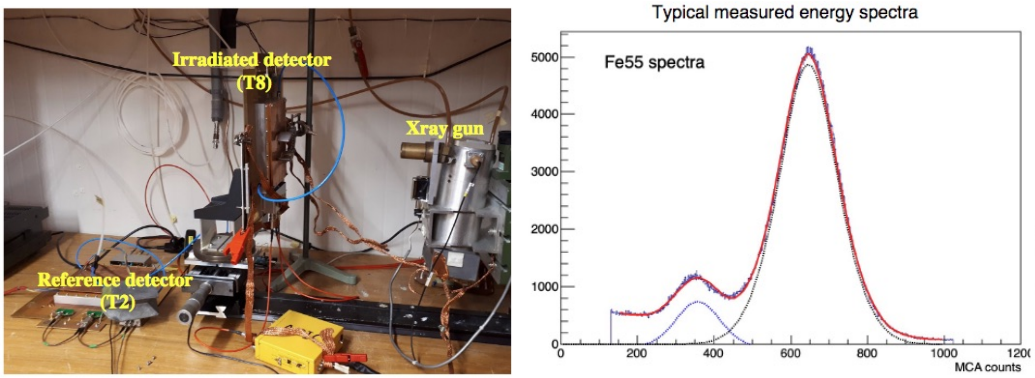

Figure 2: Left: experimental setup. Right: Example of the energy spectra of photons from an ^{55}Fe source measured with the T8 detector. The spectra is fitted with two Gaussian modelling the main and the Auger escape peak and with an exponential for the background.

The detectors have been tested with a drift field of 600 V/cm and an amplification voltage of 460 V when operated with Ar:CO_2:iC_4H_{10} and 520 V when operated with Ar:CO_2 93:7 (corresponding to an amplification field of 46 and 52 kV/cm, respectively). The gas flow was set to 1 l/h, corresponding to 2.5 renewals per hour.

The test was performed according to the following procedure: T8 has been kept under almost continuous irradiation, while T2 was not irradiated. Daily measurements, approximately at the same time, of the energy spectra with the ^{55}Fe source were performed on the two detectors, from which the gain and the energy resolution were extracted. Figure 2 right shows a typical example of the measured energy spectra from the T8 detector. During the test the detector currents have been monitored with a sampling frequency of 1 Hz and the gas parameters (relative humidity, pressure and temperature) as well as the environmental conditions were measured.

The first part of the test, with detectors operated with the Ar:CO_2:iC_4H_{10} 93:5:2 mixture, lasted about 5 months. After that the test was repeated with the Ar:CO_2 93:7 mixture to cross check the interpretation of the observed results. The test with Ar:CO_2 lasted about 2 months.

3. Results

The test with Ar:CO_2:iC_4H_{10} started in November 2021 and ended in April 2022. The total irradiation time of the T8 detector was 900 h and the accumulated charge was 1.5 C/cm^2. Figure 3 shows the current density of T8 as a function of the time (blue points) during the irradiation. On

the same plot the accumulated charge is reported (in red). Depending on the irradiation, the larger the current, the steeper the charge accumulation.

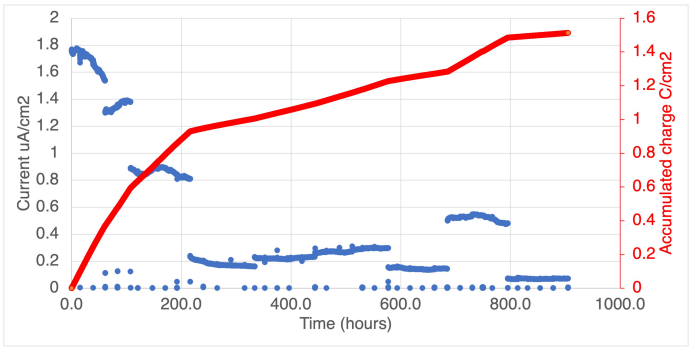

Figure 3: Current density (blue points) and accumulated charge (red points) of T8 as a function of the irradiation time.

The detector current (or, in other terms, the gain) is subject to variations owing to operating conditions, in particular the gas pressure and temperature (P and T), and it is not a good observable to study possible performance degradation. We then refer to the relative gain of T8 to the reference Micromegas T2, both extracted from the measurement of the ^{55}Fe spectra. We have verified that the relative gain is equivalent at per-mill level to the correction of the gain with P and T. Figure4 shows the relative gain ratio T8/T2 as a function of the time for the full duration of the test, with eight different periods detailed below.

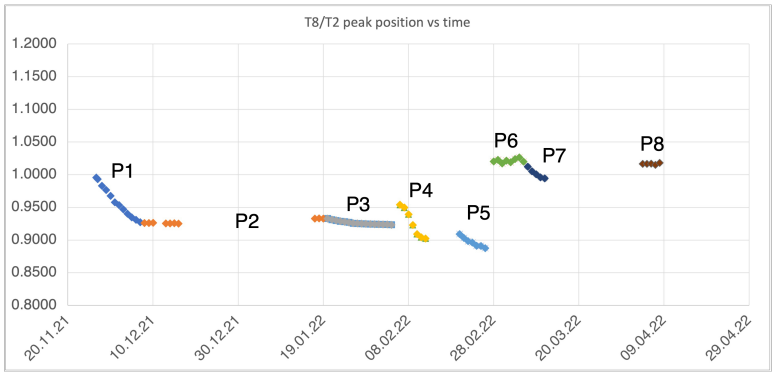

Figure 4: Gain ratio T8/T2 as a function of the time for the full duration of the test.

Period 1 T8 was operated at high rate, with current densities ranging between 0.8 and 1.7 μA/cm^2. The relative gain is observed to quickly drop from 1 to 0.927 (the initial gain ratio was 1.02, the corresponding point is not reported in the figure). The gain reduction proceeded faster at the beginning of the irradiation when the X-ray flux was higher.

Period 2 In P2 T8 was not irradiated. Gain measurements were acquired at the beginning and at the end of the period. In between, during a period of about 30 days, the HV applied to the detector was turned OFF. In the first part of P2, with no irradiation and HV ON, the relative gain resulted unchanged. After the 30 day period with irradiation off and HV OFF the relative gain was measured to increase by 0.005 (a small, although sizeable amount). In the last part of the period the HV was turned back ON and the relative gain stayed unchanged during the following three days.

Period 3 In P3 the irradiation was resumed, but at a smaller rate, about four times smaller that the last part of P1, with a current drawn by the detector of about 0.2 μA/cm^2. The gain started to decease again, but the drop is less steep when compared to P1. It is worth to notice that in periods 1 to 3 no discontinuity is observed, except the small step in P2 after the period with HV OFF.

Period 4 In P4 the irradiation was comparable to P3. Between the two periods T8 was inversely polarised (change of sign of the amplification and drift voltages) for 36 hours during which it was not irradiated. At the start of P4 the gain increased significantly and started to drop as soon as the standard irradiation was resumed.

Period 5 After P4 T8 was kept not irradiated and with HV OFF for about a week. The first measurements of P5 show a tiny increase of gain (in analogy to what observed in P2). By operating the detector under irradiation with an average drawn current of 0.5 μA/cm^2 a further reduction of the gain is measured. At the end of P5 the irradiation was interrupted and T8 was inversely polarised for 72 h.

Period 6 In P6, lasting 8 days, T8 was not irradiated and operated in standard direct polarisation. The gain was restored to the initial value.

Period 7 The irradiation in this period was at a reduced rate, with an average detector current of 0.07 μA/cm^2. A relative gain reduction is observed in that period of about 0.05. At the end of P7, the irradiation was interrupted and the inverse polarisation was applied for a week time.

Period 8 In P8 T8 was not irradiated; the gain remained stable at the very initial value.

Figure 5 shows the (uncorrected) measured energy resolution as a function of the accumulated charge for both T8 (irradiated) and T2 (not irradiated) detectors. No evidence of degradation of that performance, very sensitive to aging, is observed.

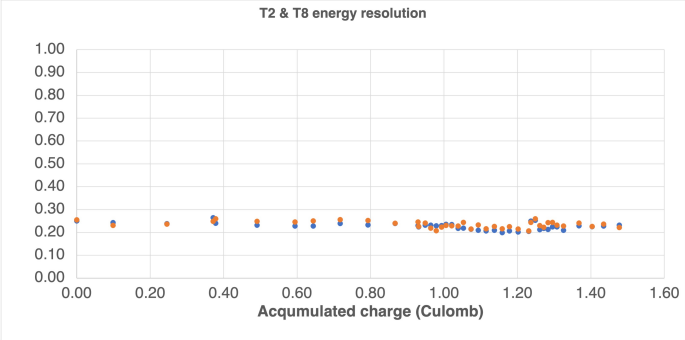

Figure 5: Energy resolution as a function of the accumulated charge for the T8 and T2 detectors.

4. Interpretation

The observation of the gain drop at the beginning of the test was worrisome and somehow puzzling, as it came along with the stability of the energy resolution. The subsequent series of tests with different irradiation intensities, periods without irradiation, period with detector OFF and with inverse polarisation was functional to clarify the observed behaviour.

Our interpretation of the result is that the gain drop is owed to charge up of the detector structure, that modifies the electric field configuration and reduces the amplification. The initial irradiation

was so intense (order of tens of MHz/cm^2) that a large amount of charge was accumulated, leading to a fast gain drop and to the fact that a period of several days without irradiation was not enough to significantly evacuate the charge, with HV kept ON. A longer period (~30 days) with HV OFF was just sufficient to recover a small fraction of the gain. By inverting the polarity the accumulated charges were effectively evacuated (in other terms, charged up with inverted charge), thus restoring the initial gain of the detector. Periods 5 to 8 have been used to verify the hypothesis, and indeed we succeeded to fully restore the detector performance at the end of the test.

A final check of the correctness of the interpretation was to repeat the test with a gas mixture that has been proven not to induce any aging effect on T8, namely Ar:CO_2 93:7. In this case the test was faster, lasting about two months with a total accumulated charge of 1.26 C/cm^2. The same phenomenology as for Ar:CO_2:iC_4H_{10} was reproduced, with a gain drop whose rate is related to the irradiation intensity, the ability to restore the initial gain by inversely polarising the detector and the stability of the energy resolution. The results of this second test are not detailed here for space limitation.

5. Conclusions

We have conducted an accelerated aging test on resistive Micromegas operated with gas mixture Ar:CO_2:iC_4H_{10} 93:5:2 and irradiated with X-rays from Cu. The duration of the test was about 5 months during which the detector under test accumulated a charge of 1.5 C/cm^2. No evidence of performance degradation due to aging was found. The observed gain reduction is interpreted owing to charge up effect and can be fully recovered by acting on the detector polarisation.

This study indicates that resistive Micromegas are more tolerant to hydrocarbons then wire chambers; a possible explanation for that is the different field configuration of the two technologies. It must be noticed that the described test was performed with a mixture containing only a small fraction of isobutane and aging effects can appear when larger concentrations of hydrocarbons are used. Finally, it must be recalled that results from accelerated tests should always be considered as an indication of possible aging phenomena in gaseous detectors, but they have to be confirmed by longevity tests performed at moderate rates. Such tests are part of our R&D program for the next future.

6. Acknowledgements

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References

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