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NUCLEAR SCIENCE AND TECHNIQUES

Nuclear Science and Techniques, Vol.17, No.5 (2006) 293–296

Performance of multigap resistive plate chamber in a γ-ray aging test

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Abstract The aging test of multigap resistive chamber (MRPC) was carried out under conditions of irradiation from a ^{137}Cs γ source facility. The total charge induced at the anode or at the cathode of the MRPC module was about 29 mC. The gamma dose rate was 10^{-2} Gy·h^{-1}, and the total accumulative radiation dose was 4.3 Gy. After irradiation, there was an obvious degradation in the properties of the MRPC module.

Key words MRPC, Irradiation dose, Aging

CLC number O572.21$^+$2

1 Introduction

MRPC is a new type of gas detector [1, 2] developed in the last few decades. It has been proposed to be a substitute for the Time of Flight (TOF) detector used in conventional technology in high-energy nuclear and particle experiments because of its properties of excellent time resolution, high efficiency, simple structure, insensitivity to magnets, and low energy dissipation. The MRPC technology has been adopted for TOF by the STAR group at Relativistic Heavy Ion Collider (RHIC). Several MRPC modules made by the High Energy Group in University of Science & Technology of China (USTC) have been operating well in physical runs for three years at RHIC. The technique of MRPC and its R&D were reported in previous studies [3, 4]. The radiation-induced aging test of MRPC is important and necessary because there are few publications regarding the same.

2 Experimental setup

2.1 Irradiation device and distribution of the radiation-induced dose rate in MRPC

The activity of the ^{137}Cs isotope source is 7.4 × 10^9 Bq. The sectional drawings of the irradiation device are shown in Figs. 1 (a) and 1 (b). There is a rectangular slot (11.5 cm × 3.5 cm) at the bottom of the lead collimator. Its open angle (60° × 20°) and the distance (20 cm) between the source and the MRPC have been optimized to make its irradiated area (23 cm × 7 cm) fit the whole MRPC. The MRPC has a sensitive area of 20 cm × 6 cm, and it includes six parallel and self-existent copper readout pads (3.1 cm × 6 cm) [3,5,6]. Its structure is shown in Fig.1 (c).

The radiation-induced dose rates in each layer of the MRPC are calculated by a Monte Carlo simulating program. The results are shown in Table1.

2.2 The test system

The test system [7], which was built in USTC for testing MRPC in the study on cosmic rays, was used to check for changes in the performance of MRPC. The MRPC consisted of a sealed aluminum box filled with a gas mixture of 5.3% iso-C_4H_{10} and 94.7% $C_2H_2F_4$. The whole test system was placed in a closed room equipped with an air-conditioner and a dehumidizer. The temperature was controlled such that it ranged from 21.0°C to 21.8°C. The other parameters of the test system were kept stable. Under normal working conditions, the MRPC usually operated in the avalanche mode at the high voltage plateau (~14 kV).

Supported by National Natural Science Foundation of China (10475074)
Received date: 2006-03-09

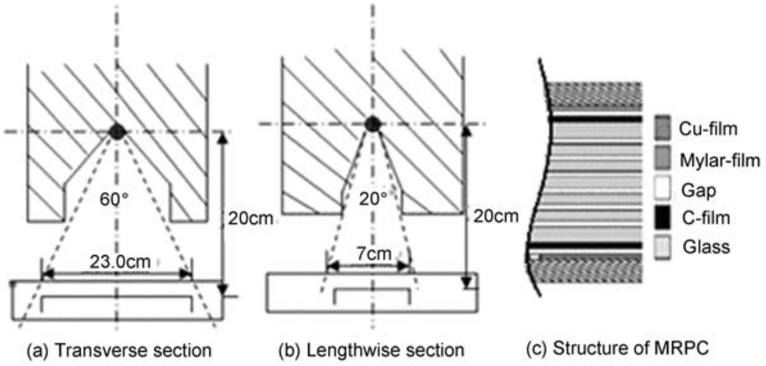

Fig. 1 Schematic diagram of the radiation source and the structure of MRPC.

Table 1 Radiation dose rate in each layer of the MRPC

Layer No.	1	2	3	4	5	6	7	8	9	10	11
Material	G 10	Cu-film	Mylar	C-film	Ex-glass	Gap 1	Glass 1	Gap 2	Glass 2	Gap 3	Glass 3
Dose rate / 10^{-2}Gy·h^{-1}	9.06	8.43	8.59	7.91	7.45	7.24	7.29	7.15	7.17	6.99	7.00

Layer No.	12	13	14	15	16	17	18	19	20	21
Material	Gap 4	Glass 4	Gap 5	Glass 5	Gap 6	Ex-glass	C-film	Mylar	Cu-film	G 10
Dose rate / 10^{-2}Gy·h^{-1}	6.86	6.94	6.80	5.97	5.18	5.19	4.91	4.92	4.72	4.52

Glass-averaged dose rate / 10^{-2}Gy·h^{-1}	Mylar-averaged dose rate / 10^{-2}Gy·h^{-1}	Gap-averaged dose rate / 10^{-2}Gy·h^{-1}	Relative error of the simulation / %
6.72	6.75	6.70*	5.5

*The value (6.7 ± 0.4) × 10^{-2} Gy·h^{-1}, which is the gap-averaged radiation-induced dose rate, was used as the reference. Because the irradiated time was 63.5 hours, the cumulative radiation-induced dose was 4.3 ± 0.2 Gy.

3 Results and discussion

3.1 Operating current

The high voltage, the flow rate of the gas, and the components were kept unchanged during the radiation-induced aging test. The operating current ranged from 0 to 1 nA before the irradiation. During irradiation, the current flowing through the multigaps increased rapidly. Finally, the γ rays from the ^{137}Cs γ source dominated the operating current of MRPC. The operating current was monitored online. The change in the the operating current with time is shown in Fig. 2. Because of the symmetric structure of MRPC, the currents passing through the anode and the cathode of HV are approximately equal.

$+I_{\rm mon}$ and $-I_{\rm mon}$ are the leak currents of the +HV and −HV, respectively, which are approximately equal to the operating currents of MRPC. Because the Mylar films between the C-films and the readouts are highly resistive and radiation-proof materials, the two loops of leak current through Mylar (PET) films to the ground can be ignored. Therefore, the operating current was about 110 nA at the beginning of irradiation, and after 63.5 h of irradiation, it increased to 140 nA. When the γ source was removed, the operating current showed an immediate, dramatic decrease, after 2 days, it became stable at 2−3 nA, showing that some aging phenomena had occurred in the MRPC.

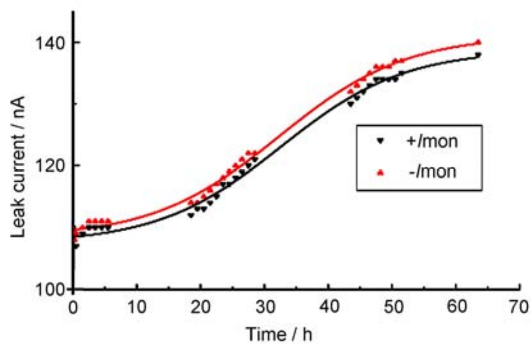

Fig. 2 Change in operating current with time.

3.2 Performance of MRPC before and after irradiation

The signals from two middle read-outs pads (Pad 3 and Pad 4) were used to depict the module performance, as shown in Table 2.

The time resolution of the MRPC showed an obvious degradation after irradiation and the proportion of the streamer signal (the signals with amplitude greater than 520 channels (measured in CAMAC) were taken as the streamer signals) increased rapidly. Therefore, under the same test condition, the MRPC module moved from the avalanche mode to the streamer mode after irradiation. This is illustrated in the ADC spectra shown in Fig. 3. The noise rate was increased by 4 orders of magnitude. The resistivity of the glass plate was 1.48×10^{13} Ω·cm before irradiation and 9.32×10^{12} Ω·cm after irradiation. The decrease in the resistivity of the glass plate after irradiation may account for the rapid increase of the noise rates. The efficiency after irradiation is a little higher than that before irradiation, which is apparent according to the definition of the MRPC efficiency [8].

Table 2 Comparison of the performance of the "J10" MRPC before and after irradiation

Phase	HV / kV	Time resolution / ps		Streamer signal / %		Noise / Hz		Efficiency / %	Leakage current / nA
		Pad 3	Pad 4	Pad 3	Pad 4	Pad 3	Pad 4		
Before irradiation	14.0	100.5	99.0	1.0	1.0	2.4	4.1	81.7	0 – 1
	13.5	87.4	99.2	0.0	1.0	1.3	1.6	79.4	
After irradiation	14.0	225.9	246.0	94.7	68.0	>10k	>10k	91.4	2 – 3
	13.5	287.6	305.1	97.2	96.9	>10k	>10k	88.0	

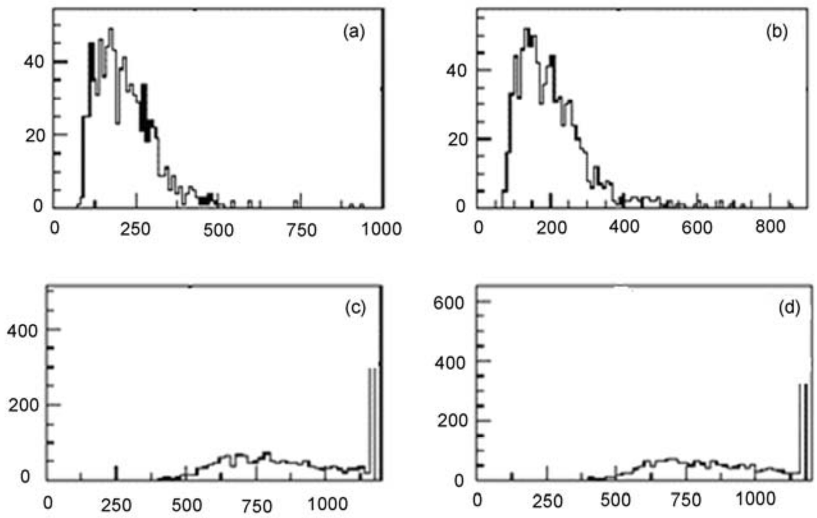

Fig. 3 ADC spectra at HV 13.5 kV.

(a) Pad 3, before irradiation. (b) Pad 4, before irradiation. (c) Pad 3, after irradiation. (d) Pad 4, after irradiation.

In the subsequent section, the physical factors accounting for the poor time resolution and high proportion of the streamer signals after irradiation are discussed.

3.3 SEM analysis of glass plates

After measurement was completed, the MRPC was disconnected. The surface of the inner glass plates of the MRPC before and after irradiation was scanned using a scanning electron microscope (SEM), and the micrographs are shown in Fig. 4.

Fig. 4 (a) is the micrograph of the glass plate before irradiation, and it shows that the surface of the plate is smooth and uniform. Fig. 4 (b) is the micrograph of the surface of the anode after irradiation, and the irregular dents that were observed were the burnt scars caused by groups of electron clusters impacting continually on the surface of the glass. Fig. 4 (c) is the micrograph of the surface of the cathode after irradiation.

When MRPC was irradiation aging, the rate of electron streamers increased [9,10]. These electron streamers could generate a plasma condition close to the surfaces of these glass plates. The working gas molecules could be decomposed and converged into some super-large organic hydrocarbons by the silicon in the glass under the plasma condition. The attachments shown in Fig. 4 (c) could be regarded as the accumulated super-large organic hydrocarbons.

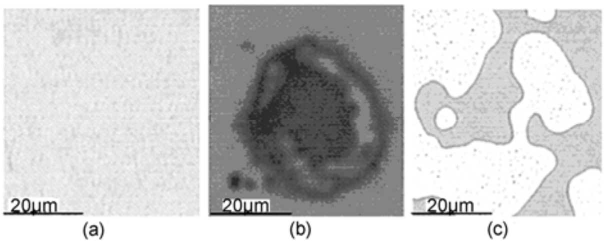

Fig. 4 SEM micrographs of the surfaces of inner glass plates before (a) and after ((b) and (c)) irradiation.

Fig. 5 is a sketch of the inner portion of the MRPC module. Fig. 5 (a) shows that before irradiation, the glass plates were parallel and uniform. When the HV was applied, the electric field among the plates was homogenous. The electric field lines were perpendicular to the plates, as shown in the inset in Fig. 5 (a). After the radiation-induced aging test, the attachment and burnt dents were generated and distributed randomly. When they were dense enough, the electric field lines among the gaps became deformed. This is shown in the inset in Fig. 5 (b). This may increase the rate of the streamer signals and lead to the decrease in time resolution. It could also be one of the reasons for the dramatic increase in noise.

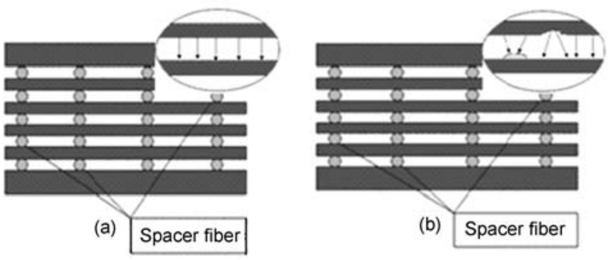

Fig. 5 Schematic diagram of the inner glass plates before (a) and after (b) irradiation aging.

3.4 GC analysis for the working gas

During the irradiation, the working gas at the entrance and the exit of the sealed aluminum box was sampled and checked by gas chromatograph (GC). The result showed that no new gas component was found in the 10^{-6} precision. This showed that in the running of MPRC, no radiation aging phenomenon was presented in the working gas, except for some deposits on the surface of the cathode plates.

4 Conclusions

An MRPC module was tested using the radiation dose rate of 6.7×10^{-2} Gy·h^{-1} for about 63.5 h. The total charge induced at the anode or the cathode of the MRPC module was about 29 mC. Comparing the performance of the MRPC module before and after irradiation, the aging phenomenon in the MRPC was attributed to the burn scars on the anode and the deposits on the cathode, which lead to the increase in streamer signals in the gaps of the MRPC. Further experiments on the radiation aging test of MRPC will be carried out in future.

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