Performance of μ-RWELL detector vs resistivity of the resistive stage

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1. Introduction

The μ-RWELL is a compact spark-protected single amplification stage Micro-Pattern-Gaseous-Detector (MPGD). The detector amplification stage is realized with a polyimide structure, micro-patterned with a dense matrix of blind-holes, integrated into the readout structure. The anode is formed by a thin Diamond Like Carbon (DLC) resistive layer separated by an insulating glue layer from the readout strips. The introduction of the resistive layer strongly suppressing the transition from streamer to spark gives the possibility to achieve large gains (> 10^4), without significantly affecting the capability to be efficiently operated in high particle fluxes. In this work we present the results of a systematic study of the μ-RWELL performance as a function of the DLC resistivity. The tests have been performed either with collimated 5.9 keV X-rays or with pion and muon beams at the SPS Secondary Beamline H4 and H8 at CERN.
means of the readout electrodes (3D-current evacuation) is under study for high-rate purposes. In this paper we focus on the single-resistive layout.

2. Detectors description

The three prototypes used in this work are single-resistive layer detectors with DLC layer resistivity of 12/80/880 MΩ/□. One of the major difference of such detectors with respect to the first version of the μ-RWELL [1] is that the copper dots, patterned on the bottom side of the foil in correspondence of each WELL structure, have been removed thanks to the use of the DLC that ensures a high chemical and mechanical stability. Moreover a global irradiation test at the GIF++ CERN facility is in progress to study possible aging effects on the DLC. All prototypes under study were equipped with a readout patterned with a 400 μm pitch strips. In Table 1 the characteristics of the prototypes are reported.

2.1. DLC sputtering

Sputtering is commonly used to deposit thin protective films on a substrate. For the production of our detectors, a large industrial sputtering chamber in Be-Sputter Co., Ltd. (Japan) has been used. The carbon is sputtered on the Kapton® foil as an amorphous DLC using a pure graphite target. The resistivity dependence as a function of the DLC thickness for different sputtering batches is shown in Fig. 4. The MM calibration curve has been obtained by sputtering the DLC on a brand-new Kapton® foil [8].

The two open square markers, referring to the μ-RWELL 2017 test production, for which the base material has been pre-dried in an oven (200° for approximately 2 h), match the MM calibration curve. The dropping curve refers to the 2016 test production. The different trend for the two curves is assumed to be related with the humidity trapped by the Kapton® before the sputtering process.

3. Laboratory tests

The characterization of the detectors is performed with collimated 5.9 keV photons generated by an X-ray gun (PW2217/20 Philips). The gas gain of the detectors has been measured in current mode: the current drawn at a given potential through the resistive layer has been normalized to the ionization current, recorded operating the detector at unitary gain (very low voltage). The gain has been then plotted as a function of the amplification potential. As shown in Fig. 5, the gas gain of the various detectors, measured for the Ar:i-C₄H₁₀ (90:10 vol%) gas mixture, and parametrized as $G = e^{\alpha \Delta V - \beta}$, is typically ≥ 10000, being stopped when current instabilities (not discharges) are observed:¹ the largest gain is generally reached by the detector with highest resistivity. The rate capability has been measured at the gain $G=\sim 4000$, well above the knee of the efficiency plateau (Section 4). The X-ray gun can provide photon-converted signal rate ranging from 1 kHz up to approximately 300 kHz. The equivalent flux is obtained by dividing the measured rate

¹ As shown in Fig. 9 of [1].
Table 1

<table>
<thead>
<tr>
<th>Detector characteristics</th>
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<th>Detector n.2</th>
<th>Detector n.3</th>
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<td>DLC resistivity MΩ/□</td>
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<td>880</td>
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<td>Readout strip pitch (mm)</td>
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<td>0.4</td>
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</table>

Fig. 5. Measured gain for the three detectors at STP.

Fig. 6. Normalized gain for 12 MΩ/□ (open squares), 80 MΩ/□ (full circles) and 880 MΩ/□ (open circles).

Fig. 7. Rate capability as a function of the H8-SPS CERN pion beam flux for two different zones of a large area single layer µ-RWELL. The two zones have been operated at different gains as shown by the fit lines.

Fig. 8. Tracking efficiency as a function of the gain for the three detectors.

by the irradiated area, given by the collimator surface ² and for each flux we have plotted the ratio of the measured gain to the nominal gain at low rate (Fig. 6). The points are fitted with the function

\[
\frac{G}{G_0} = \frac{-1 + \sqrt{3}\phi_0}{2\phi_0}\Psi \tag{1}
\]

introduced and derived in the appendix A of [1]. Reverting the Eq. (1) we can obtain the value of the flux at a given normalized gain drop of 3%, representing our definition of the detector rate capability. As expected, the gain decrease is correlated with the voltage drop due to current through the resistive layer: larger the DLC layer resistivity, the lower is the rate capability, ranging, for local irradiation, from few tens of kHz/cm² up to few MHz/cm², even though in case of global irradiation and large area detector we expect a rate capability much lower than the values measured with collimated X-rays.

A more realistic measurement of the rate capability has been obtained irradiating with a pion beam, with a spot area of approximately 3 x 3 cm² (FWHM), two different zones of a further single-resistive layer detector (∼ 1.2 x 0.5 m²) with a ∼ 70 MΩ/□ resistivity. The result reported in Fig. 7 shows that the two zones can be operated up to 35 kHz/cm² without appreciable gain losses.

² We performed a local irradiation of the detector with a 2.5 mm diameter brass collimator.

4. Beam test results

The tracking performance of the three detectors has been investigated at the H4-SPS CERN muon beam. The setup has been composed of four trigger scintillators (two read-out with Silicone Photomultipliers and two with Photomultiplier tubes) and two tracking stations
The narrower residuals distribution, Fig. 10, for the 80 MΩ/□ prototype has been obtained at a gain G~4000 with orthogonal tracks showing a standard deviation of 69 ± 1 μm. Subtracting the contribution of the external trackers (σ_fit = 47 ± 5 μm), evaluated from the average width of their residuals, a spatial resolution of 52 ± 6 μm has been derived.

Eventually, as reported in Fig. 11, the space resolution depends on the resistivity of the DLC, showing a minimum around a surface resistivity of about 100–200 MΩ/□. At low surface resistivity the charge distribution loses the typical Gaussian shape and consequently the σ becomes larger. At high surface resistivity the charge dispersion is so negligible (the strip cluster size being close to 1) that the charge centroid method becomes no more effective and the σ approaches the limit of pitch/√12.

5. Conclusions

In this work we have discussed the results of a systematic study of μ-RWELL performance as a function of the DLC resistivity. All the detectors, realized with the single-resistive layout, exhibit a gas gain up to and above 10^4 with Ar:i-C_4H_{10} (90:10 vol%) gas mixture. A rate capability up to 35 kHz/cm^2 has been measured and a spatial resolution better than 100 μm has been obtained, showing a minimum between 100 and 200 MΩ/□.

References


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3 The tracking efficiency is defined as the ratio of the good cluster of fired strips in the μ-RWELL to the total number of good tracks (reconstructed by the four external trackers); the good clusters are chosen to be inside ±3σ of the residuals distribution.

4 Defined as x/fit = x meas, where x/fit is the intersection of the track, reconstructed with three detectors, with the excluded one and x meas is its cluster centroid coordinate.