Small-pad Resistive Micromegas: Comparison of patterned embedded resistors and DLC based spark protection systems.

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Abstract. We present the development of resistive Micromegas aiming at operation under high rates, up to tens MHz/cm\textsuperscript{2}, focusing on the optimisation of the spark protection resistive layer and the miniaturisation of the readout elements. Several Micromegas detectors have been built with an anode plane matrix of 48x16 rectangular readout pads, each pad 0.8x2.8 mm\textsuperscript{2}. The detectors differ for the spark protection resistive schemes being realised with the following techniques: a pad-patterned embedded resistor by screen printing, and uniform DLC (Diamond Like Carbon structure) layers.

Characterisation and performance studies of the detectors have been carried out by means of radioactive sources, X-Rays, and test beam. A comparison of the performance obtained with the different resistive layouts is presented, in particular focusing on the response under high irradiation and high rate exposure.

1. Introduction
Resistive Micromegas are built with parallel plate electrodes structure, with the volume divided into two gaps (drift and amplification) by means of a metallic mesh. The anode plane hosts the read-out elements, usually strips, built using Printed Circuit techniques. For high rates applications and/or intense flux of highly ionising particles, discharges effects are greatly mitigated with the implementation of a layer of resistive strips facing the amplification gap [1]. This is, for example, the solution adopted by ATLAS for the New Small Wheel upgrade, for operations up to few kHz/cm\textsuperscript{2} [2]. To further improve the rate capability, up to tens MHz/cm\textsuperscript{2}, the miniaturisation of the readout elements and a new scheme of the resistive protection system are required.

2. Description of the different resistive schemes.
All Small-pad Micromegas detectors presented in this paper consist of a similar anode plane, segmented with a matrix of 48x16 readout pads. Each pad has a rectangular shape (0.8x2.8 mm\textsuperscript{2}) with a pitch of 1 and 3 mm in the two coordinates. The active surface is 4.8x4.8 cm\textsuperscript{2} with a total number of 768 channels, routed off-detector for readout. The layout of the anode plane can be seen in Fig. 1–top-left. On top of this anode plane, two different concepts of the
spark protection resistive layer have been implemented. The first one adopts a pad-patterned resistive scheme [3, 4, 5, 6]. It relies on the anode pads being overlaid by resistive pads, interconnected by intermediate “embedded” resistors as shown in Fig. 1–bottom-left. The total resistance between the resistive and anode pads is in the range 3-7 MOhm. The second one uses two continuous resistive layers of Diamond Like Carbon structures (DLC), deposited by sputtering on Kapton foils and glued on the anode. The two resistive layers are interconnected together with the readout pads with a network of conducting vias with a few mm pitch, filled with silver paste, to evacuate the charge, as sketched on the right part of Fig. 1. Actually, the detector active plane was divided in two halves, each one having a different pitch of the conducting vias through the DLC layers: 6 mm and 12 mm respectively. The spark protection mechanism with a double DLC layer was inspired by the technique used for the development of µ-RWELL detectors prototypes [7].

The detectors are finally completed with a bulk Micromegas process [8], defining the 128 µm amplification gap with a metallic micro-mesh supported by Pyralux insulating pillars, and with a drift cathode defining the 5 mm wide conversion gap.

In the following, the detector built with the pad-patterned technique will be referred to as PAD-P. Exploiting the DLC technique, two detectors have been built with different resistivity: the first one with resistivity in the range 50–70 MOhm/sq and the other with foils with about 20 MOhm/sq, referred to as DLC50 and DLC20, respectively. In order to distinguish the two regions with 6 mm and 12 mm vias pitch, the suffix “6-mm” and “12-mm” are added to the corresponding name of the DLC detectors.

![Figure 1. Top-left: Photo and Layout of the anode plane PCB; Bottom-Left: side view sketch of the pad-patterned resistive scheme; Right: side view sketch of the DLC detectors. The drift gap and cathode plane are not shown in the sketches. Dimensions are not to scale.](image)

3. Comparison of the Detectors Performance.
Performance studies have been carried out with radioactive sources (55Fe), with a X-Rays gun and with high energy particle beams at CERN. All the detectors have been operated with the ageing-free gas mixture Ar/CO₂=93/7, with a nominal setting of 300 V across the 5 mm drift gap. In the case of the high rates performance, the 3 detectors have been tested at the same gain condition, tuning the HV value to obtain a gain of \( \sim 8000 \) (at 100 kHz).

A review of the results obtained with the detector using the pad-patterned screen printed resistive layer (PAD-P) can be found in [6]. It turns out to be a robust detector, without any indication of early discharges, but with some limitations in energy and spatial resolution. In order to improve the performance on energy and spatial resolution, as well as, to exploit new construction techniques, the “DLC” detectors have been built, in the configurations summarised in Sect. 2.
In Fig. 2 the spectra measured exposing the PAD-P detector (left) and the DLC50 (right) to a $^{55}$Fe radioactive source are reported. From the most prominent peak (from 5.89 keV Mn K$_{\alpha}$ X-rays) an energy resolution of 48% and 29% (FWHM) are measured for the PAD-P and DLC50 detectors, respectively. Due to pad border effects and non-uniformity of the resistive layer, the PAD-P detector shows a modest energy resolution, though not essential in many applications as tracking device. The use of the DLC uniform resistive layers significantly improves the resolution and it has no dependence on the position.

Figure 2. Multi Channel Analyser spectra from a $^{55}$Fe source obtained for the PAD-P (left) and DLC50 (right) detectors.

Charging-up effects have been studied by measuring the detector current (proportional to the gain) as a function of time, with cycles of X-Ray irradiation at increasing rates. An example of the obtained results is reported in Fig. 3. While a drop of about 20% is observed in the PAD-P detector, after few seconds after the start of irradiation, the DLC detectors do not show any charging up effect. This was indeed expected from the uniformity of the resistive layer, and the fact that there is no exposed dielectric, with the exception of pillars.

Figure 3. Detector current as a function of time for PAD-P (left) and DLC50 (right) under cycles of irradiation with X-rays.

Tests with X-Rays have been carried out to explore the high rates performances. A calibration procedure must be adopted to obtain the actual conversion rates of X-rays in the detector, which should be unaffected by efficiency loss and/or electronics signal processing effects. The rates are measured from the signals from the mesh with a discriminator and counter system, as well as with the MCA, in conditions of linearity. That is when the response of the detectors are linear in gain and the effects of pile-up in the discriminator and in the MCA are negligible (or can be accounted for with the estimated dead-time). These conditions applies for X-ray gun currents corresponding to measured rates up to about 200 kHz. For higher X-ray currents, the
rates deviate from linearity, and are thus extrapolated from the fit at lower rates. This “rate calibration procedure” is repeated for all detectors at any change of measurement conditions (e.g. change of amplification voltage or exposure area dimensions).

In Fig. 4 the comparison between the configurations DLC20, DLC50 (both in the 6 mm pitch region of the grounding vias) and PAD-P is reported. The plots show the detectors measured currents as a function of the extrapolated rates, both normalised to unit area. Data are taken with a shielding defining an almost uniform irradiated area in a circle of 1 cm of diameter (0.79 cm²). In the left panel the response of the detectors for rates up to about 10 MHz/cm² is shown. DLC20 shows a significantly better behaviour than DLC50, as expected from the lower resistivity. In this region, PAD-P shows a deviation from linearity of about 25%, due to the combination of charging-up and ohmic drop. In the right panel the response at very high rate is shown. The PAD-P and DLC20 configurations have a comparable behaviour in the full explored region (up to about 90 MHz/cm²). The ohmic drop of DLC50, due to its high resistivity, increases with rates.

**Figure 4.** Mesh current as a function of rate, both normalised to unit area, for different prototypes and configurations of the resistive protection scheme, exposed to X-rays on a surface of 0.79 cm². Left: for rates up to about 10 MHz/cm²; Right: in the extended region of rates above 100 MHz/cm².

The comparison between the configurations with 6 mm and 12 mm pitches of the grounding vias for DLC50 is reported in Fig. 5. A maximum difference within 10% is measured at about 9 MHz/cm² (left panel), the difference significantly increases at higher rates (right panel).

**Figure 5.** Mesh current as a function of rate, both normalised to unit area, for the two configurations DLC50-6mm and DLC50-12mm (with different vias pitches), exposed to X-rays on a surface of 0.79 cm². Left: for rates up to about 10 MHz/cm²; Right: in the extended region of rates above 100 MHz/cm².
All measurements shown so far are related to an exposed surface of 0.79 cm$^2$. In order to study the dependence of the detectors response on the irradiated area, shields with different apertures have been used. In Fig. 6 the normalised currents, for PAD-P (left) and DLC50–6mm (right) are reported. PAD-P doesn’t show any significant difference up to rates of 8 MHz/cm$^2$, the maximum reached for the large area irradiation. At this rate the current was about 18 µA for 12 cm$^2$, close to the power supply limit. The measurements for the large area (12 cm$^2$) was limited at 0.7 MHz/cm$^2$ for the DLC50–6mm detector due to the onset of discharges. In the measured range no dependence on the irradiated area has been observed in the comparison of 0.79 and 12 cm$^2$ exposures.

At high rates, in the region of ten MHz/cm$^2$ the dependence on the irradiated area is not yet a concluded study. While PAD-P show no dependence, and this is expected due to its structure with each pad being independent from the others, for the DLC, the uniform resistive layers can potentially induce more severe drops the larger the exposed area.

![Figure 6](image6.png)

**Figure 6.** Mesh current as a function of rate, both normalised to unit area, for different irradiated areas, for the PAD-P (left) and DLC50–6mm (right) detectors.

An indication of a dependency on the irradiated surface can be seen for DLC50–6mm in Fig. 7 in the comparison of exposures on 0.07 cm$^2$ (hole with 3 mm diameter), 0.79 cm$^2$ (hole with 10 mm diameter) and 3.61 cm$^2$ (square with side 19 mm). For this test, data have been taken with DLC50 detector operated at a gain about a factor 2 higher than the previous test. A deviation from a common behaviour is observed above few MHz/cm$^2$.

![Figure 7](image7.png)

**Figure 7.** Mesh current as a function of rate, both normalised to unit area, for DLC50–6mm and different irradiated areas.

Finally, a comparison of results is reported in Fig. 8 from data taken with high energy muon beam at the H4 SPS Experimental area at CERN, in October 2018. The left panel shows the cluster size for the three detectors, PAD-P, DLC50 and DLC20, as a function of the
amplification voltage. As expected, the cluster size is higher for the detectors with uniform resistive layers and increases as lower is the resistivity. In Fig. 8-right, the spatial resolution along the precision coordinate (1 mm pad pitch) is reported as a function of the amplification voltage. The homogeneity of the resistive layers, along with the higher cluster size, are probably the key parameters to obtain a significantly better resolution with respect to the pad-patterned detector. For both DLC20 and DLC50 the resolution is below 100 \( \mu \text{m} \). Specifically, DLC20 reaches 80 um resolution (10-20\% better than DLC50) with a higher cluster size.

![Figure 8. Comparison of test beam results for PAD-P, DLC20 and DLC50. Cluster size (left) and Spatial resolution (right) as a function of the amplification voltage.](image)

4. Conclusions.

Preliminary data have been shown for different pixelated Micromegas resistive detectors. Despite developing charging-up (saturating with a gain drop of about 25 \%), the pad-patterned detector shows excellent response up to rates as high as hundred MHz/cm\(^2\) from X-rays. It has a response independent on the exposed surface to radiation, and it is very robust. The DLC detectors have significantly better performance for what concerns the energy resolution and the spatial resolution. They do not suffer from charging-up effects, and, with an optimised configuration (e.g. DLC20–6mm - see Fig. 6), the response is similar to PAD-P for high rates. Onset of discharges have prevented us to study these detectors up to very high rates and large exposure areas. The weakness of these detectors has been traced to be due to a particular step in the production process. One of the main goals of the next generation of prototypes is the construction of DLC with a new technique focusing on robustness.

References

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