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The micro-RWELL detector for the phase-2 upgrade of the LHCb Muon system

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The micro-RWELL is a single amplification stage resistive Micro-Pattern Gaseous Detector, realized with a copper-clad polyimide foil patterned with a micro-well matrix and coupled with the readout PCB through a DLC resistive film (10 ÷ 100 MOhm/□). The detector is proposed for several applications in HEP that require fast and efficient triggering in harsh environment (LHCb muon-upgrade), low mass fine tracking (FCC-ee, CepC) or high granularity imaging for hadron calorimeter applications (Muon collider). For the phase-2 upgrade of the LHCb experiment, proposed for LHC Run-5, the excellent performance of the current muon detector will need to be maintained at 40 times the pile-up level experienced during Run-2. Requirements are challenging for the innermost regions of the muon stations, where detectors with rate capability up to 1 MHz/cm^2 and capable to stand an integrated charge up to 10 C/cm^2 are needed. In this framework an intense optimization program of the micro-RWELL has been launched in the last years, together with a technology transfer to the industry operating in the PCB field. In order to fulfill the requirements, a new layout of the detector with a very dense current evacuation grid of the DLC has been designed. The detector, co-produced by the CERN-EP-DT-MPT Workshop and the ELTOS Company, has been characterized in terms of rate capability exploiting a high intensity 5.9 keV X-ray gun with a spot size (10 ÷ 50 mm diameter) larger than the DLC grounding-pitch. A rate capability exceeding 10 MHz/cm^2 has been achieved, in agreement with previous results obtained with m.i.p. at PSI.

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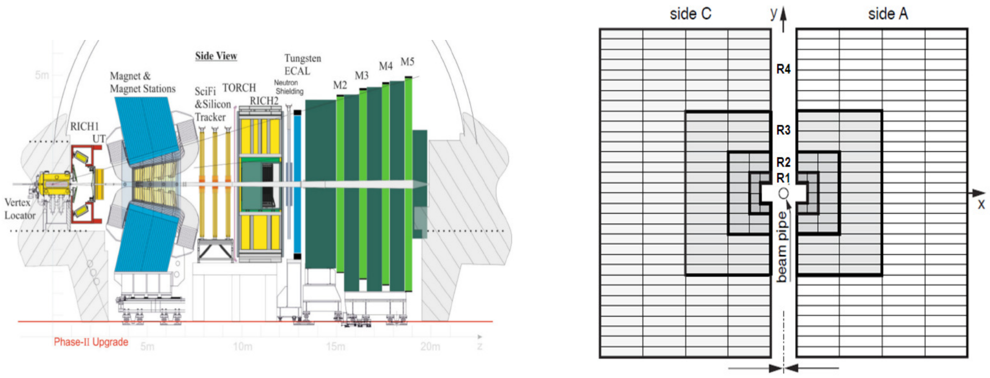

Figure 1: Sketch of the LHCb apparatus (left) and overview of the regions of each muon station (right).

1. Introduction

In view of the High luminosity runs, the LHCb collaboration is working at the upgrades of the apparatus. In particular, the MultiWire Proportional Chambers of the present detectors will need replacement because of the expected higher rate. For the innermost regions R1 and R2 we are proposing the use of micro-Resistive WELL (μ-RWELL) detector.

2. The LHCb upgrade

For Run 5-6, nowadays scheduled in the years 2035-2042, the instantaneous luminosity of the accelerator LHC will be increased to $1.5{\cdot}10^{34}$ cm^{-2} s^{-1}, at least a factor 10 with respect to the luminosity delivered in Run 1-2. As a consequence, the rates expected in the muon stations will be larger: an estimate is summarized in tab. 1 (left). The present muon stations, composed of MultiWire Proportional Chambers, cannot cope with the rates expected in R1 and R2. The LHCb collaboration is carefully investigating the possibility to replace the devices in these regions with a more suitable technology, able to maintain the efficiency plateau at these rates. A helping hand is given by the field of Micro-Pattern Gaseous Detectors (MPGD), where recent developments on resistive layers gave birth to the micro-Resistive WELL (μ-RWELL) detector.

Rates (kHz/cm^2)	M2	M3	M4	M5
R1	749	431	158	134
R2	74	54	23	15
R3	10	6	4	3
R4	8	2	2	2

Area (m^2)	M2	M3	M4	M5
R1	0.9	1.0	1.2	1.4
R2	3.6	4.2	4.9	5.5
R3	14.4	16.8	19.3	22.2
R4	57.6	67.4	77.4	88.7

Table 1: On the left: maximum expected rate in the region of each muon station and region (see fig. 1 (bottom). The M1 station has been removed after Run 2. On the right: areas of the regions of each muon station.

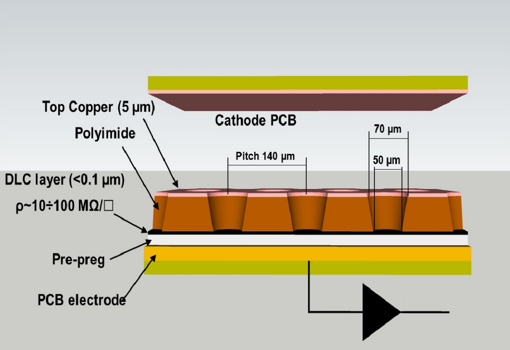

Figure 2: A cross-section of the µ-RWELL-PCB with the geometrical and phyisical parameters.

3. The µ-RWELL technology

The micro-Resistive WELL [3] technology has the advantage to be a compact and simple-to-assemble detector being at the same time equipped with a resistive layer to quench the spark amplitude. It is composed of three elements: a frame, a cathode and the µ-RWELL_PCB. The frame defines the thickness of the gas gap, actually the active gas volume where the ionization occurs: for all detectors here described the thickness of this gap is 6 mm; the cathode establishes the electron field to make the free electrons drift towards the last component: the µ-RWELL_PCB, the core of the detector. It is a Printed Circuit Board (PCB) containing the amplification stage, the resistive layer and the segmented readout plane. The first is very similar to a GEM foil (fig. 2): a 50 µm thick kapton foil (Apical®) clad on one side with 5 µm Cu and sputtered on the opposite surface with Diamond-Like-Carbon (DLC) to obtain a thin layer (~ 100 nm) with surface resistivity ρ_S between 10 and 100 MΩ/□. The introduction of a resistive stage in Micro-Pattern Gaseous Detectors starts in 2009 [4] and exploits the same principle used in streamer tubes [5] and RPCs [6]: the charge is driven to the resistive layer and flows to the ground with a given time τ [7] inducing signals on the underlying readout strips/pads. This time τ strongly affects the rate capability of the detector because of a local charging-up. In case of discharge this effect lowers the amplification field then stopping its propagation but at the same time switching off that part of the detector. The resistivity of the DLC is then a crucial point: a large resistivity makes the detector safer but increases the earlier mentioned τ then worsening the rate capability of the detector; a low resistivity plays an exactly complementary role: larger rate capability but lower discharge quenching power.

4. The µ-RWELL evolution

Studies have been focused on the DLC grounding layout (also called in the following *charge evacuation scheme*) with the purpose to increase the rate capability while maintaining a safe resistivity. A first layout is shown in fig. 3 (top, left) where the DLC grounding is provided all around the active area. Starting from the characterization of this prototype irradiated under X-rays we proposed a simplified model [3] relating the rate capability of the detector to the main features of the gas mixture, ρ_S and the irradiated area. To increase the rate capability of the detector we introduced a grounding network also in the active area: the evolution of the models are shown in

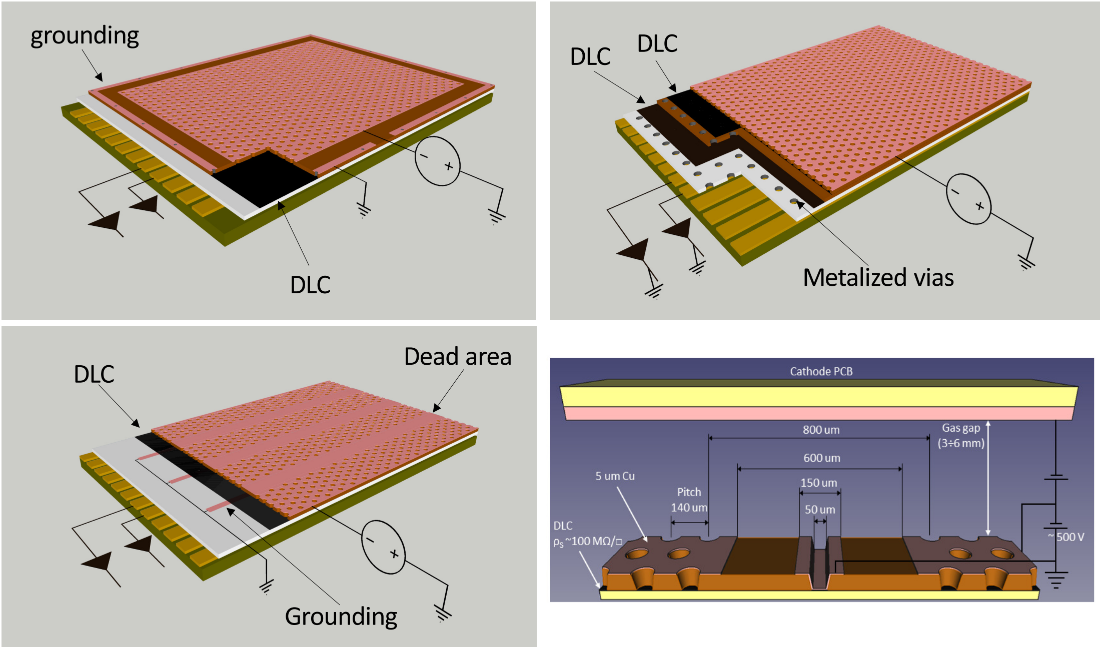

Figure 3: The evolution of the µ-RWELL technology: the low-rate version (top left), the Double Layer (top right), the Silver Grid (bottom left) and the PEP (bottom right).

fig. 3. First evolution, as swhon in fig. 3 (top, right), is the Double Resistive Layer (DRL) where a second resistive layer has been introduced. The two layers are interleaved by a gluing film, 50 µm thin, and connected by a matrix of metalized vias. The same scheme applies between the second layer and the readout plane, glued with a pre-preg adhesive film, paying attention to stagger the two matrices: the last plane provides the final grounding to the whole resistive stage. This version is the first where a particular attention has been paid to the minimum distance between the grounding node and the amplification channels, in the following defined as DOCA (standing for *Distance Of Closest Approach*). Although this prototype exhibited a rate capability up to 10 MHz/cm^2, its manufacturing is quite complex and not reliable for a technological transfer to industry, where a simplified procedure is preferred. To meet this request a second version of the detector has been built and sketched in fig. 3 (bottom, left): the Silver Grid (SG). The grounding network is created with copper strips realized by photolitography below the DLC: the base material is indeed a stack of copper, kapton, DLC and copper again. To increase the DOCA a dead area is present above the grounding strips. The alignment of these dead areas with the strip can be difficult in particular when going toward large area devices. This issue suggested a different procedure to obtain the grounding of the DLC, exploiting the already planned operation to open the amplification channels by a chemical etching. The active area is discontinued by grooves that uncover the DLC; then a copper plating, carefully separated from the copper in the active sectors, is disposed to connect the DLC to the ground. The process is quite improved with respect to the Silver Grid because the alignment between these grooves and the active sectors is provided when printing the mask for the photoligraphic patterning of the upper copper. After patterning, the etching follows and eventually

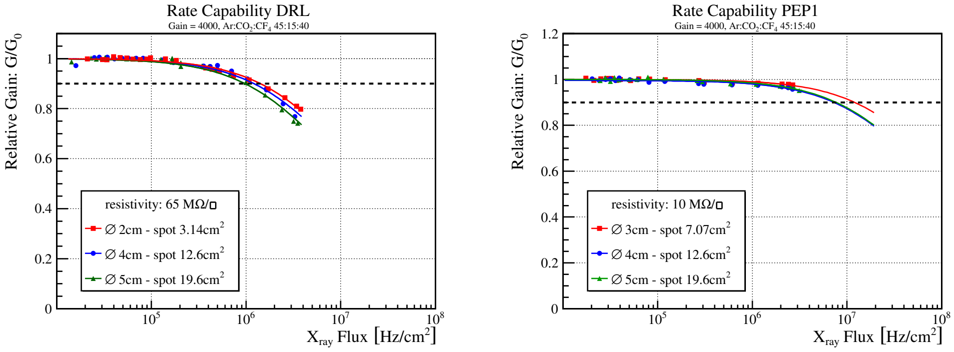

Figure 4: Rate capability measured with 5.9 keV X-rays with Double Layer µ-RWELL (left) and with PEP (right).

the plating: that is why the version is called PEP (fig. 3 (bottom, right). In practice the active area of the device is divided in sectors, so that to validate this charge evacuation scheme layout it is enough to study the behaviour of one sector.

5. X-rays measurements

The prototypes have been all characterized under high intensity X-ray Philips 2217/20 gun. The detectors have been flushed with Ar:CO$_2$:CF$_4$ 45:15:40. In this mixture the 5.9 keV X-rays produce a ionization about 3 times larger than the one given by a m.i.p. in the 6 mm thick gas gap. The plots in fig. 4 show that for a Double Resistive Layer (left) the ratio of the measured gain to the nominal one drops down to 90% for a photon flux around 1 MHz/cm^2, which corresponds to a m.i.p. rate of 3 MHz/cm^2. The PEP (right) shows a relative gain drop of 10% at flux 7 times larger, according to the extrapolation of the fitting function since such flux is out of the range of our gun. The measurements have been performed with different collimators with the purpose to compare the detector response as a function of the irradiated area. As expected the larger the irradiated area the worse is the rate capability with a saturation effect due to the fact that in PEP the sector width is 1 cm and larger collimators do not affect any longer the behaviour of the single sector.

6. Technological transfer

As reported in tab. 1 (right), the areas to be covered require a huge number of detectors and this can be afforded only if part of the production is completed by the industry. Along the years a technological transfer has been carried on in collaboration with ELTOS S.p.A, a well established company in PCB production. The company receives from the Be-Sputter Ltd. (Japan) the base material, a 50 µm Apical®clad with copper and sputtered with DLC, and delivers, after a dedicated and deeply discussed procedure, the µ_RWELL-PCB to be shipped to CERN for the opening of the amplification channel by chemical etching. Recently the same company operated an optical metallographic survey to check the manufacturing of the PCB (fig. 5)

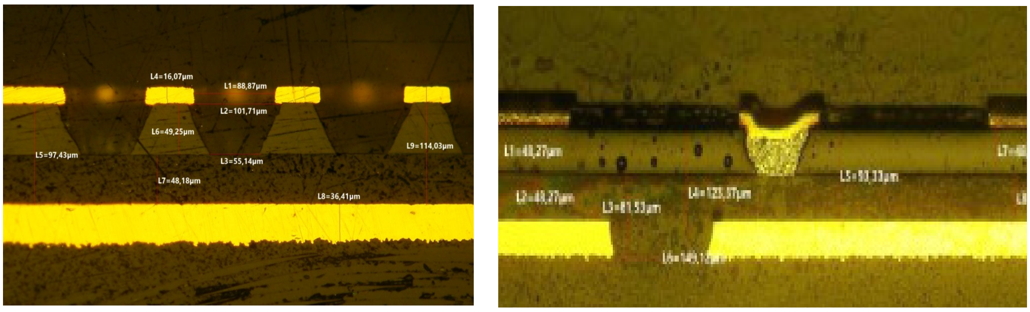

Figure 5: Optical metallographic inspection of the µ-RWELL. The plating of the groove for a PEP is well visible on the right.

7. Beyond HEP

The µ-RWELL technology finds room in several applications even beyond the High Energy Physics. Low rate versions have been proposed for the ATTRACT-uRANIA European and uRANIA-V projects, focused on the development of neutron detectors for the Radiation Portal Monitors; the IDEA apparatus at FCC_ee involves the technology for the construction of its pre-shower and muon system; micro-RWELL will be realized for the upgrade of CLAS12 at JLAb; TACTIC and X17 are using these detectors for neutron detection and the search of light boson, respectively.

8. Conclusions

The development on µ-RWELL technology led to versions able to stand up to 10 MHz/cm^2 losing less than 10% in gain, meaning a negligible efficiency leak, according to the measurements done so far. The future plans have in schedule a long-term test with an eco-friendly gas mixture (Ar:CO_2:iC_4H_{10} 68:30:2) and measurements of the time resolution.

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