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Pixelated Resistive MicroMegas for High-Rates Environment

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The new era of Particle Physics experiments is moving towards new upgrades of present accelerators (Large Hadron Collider at CERN) and the design of high energy (tens/hundreds TeV scale) and very high intensity new particle accelerators (FCC-ee/hh, EIC, Muon Collider). Cost effective, high efficiency particle detection in a high background and high radiation environment is fundamental to accomplish their physics program.
Micromegas (MM) is now a mature technology for HEP experiments. In ATLAS, large size resistive MM [1] will be employed in the upgrade of the Muon Spectrometer in 2020 (New Small Wheel Atlas project [2]) and will operate at moderate hit rate up to about 20 kHz/cm^2 during the HL-LHC phase.
Resistive MM 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 (the PCB) hosts the read-out elements, usually strips, built using PCB techniques. The term 'resistive' refers to the presence of a resistive plane of strips on top of the readout plane, with a kapton foil as insulator in between. This solution reduces possible discharges, quenched by the resistive layer, without spreading too much the avalanche footprint while keeping a high efficiency detector (>98%). Since 2015, our research team is working to a further development of the MM technology to reach stable and efficient operation up to particle fluxes of 10 MHz/cm^2, with low occupancy and good stability and robustness. To increase the rate capability of about three order of magnitude than nowadays we designed a detector with finer granularity through the use of readout pads of only a few mm^2 area. This choice significantly reduces the occupancy of the readout elements, but the resistive structure required for the spark protection needs to be optimized to avoid losing efficiency at very high rates.
In particular, several prototypes (formed by 748 pads organized with a pitch of 1×3 mm^2 and covering a total active area of 4.8×4.8 cm^2) have been designed and built (in collaboration with the CERN Micro-Pattern Technologies -MPT- Workshop) using two different resistive schemes:

- The "embedded resistors pad-patterned" (PAD-P) technique [5], inspired by former R&D projects [3,4], consists in stacking to each metallic readout pad other two resistive pads (screen printed with a suitable resistive paste) interspersed with an insulating kapton layer; the innermost pad (facing the gas gap) is then electrically connected to the middle one, that is in turn connected with the outermost pad (the metallic one); both connection vias are made by micro-holes filled with silver paste. In this way each middle pad acts as a resistor, totally separated from the neighbours, whose value ranges between 5 and 7 MΩ, depending on the paste resistivity.
- The "DLC" technique (inspired to the technique used for the μ-RWELL detector [6]) takes its name from the use of the Diamond Like Carbon surface treatment. This consists in sputtering carbon (evaporated from a graphite target) on a kapton foil, obtaining a uniform resistive layer. Two DLC foils are then interconnected through staggered conductive vias, providing the charge evacuation through their resistive surface. The pitch of the conductive vias network represents a relevant parameter of the detector, as long as the surface resistivity of the DLC foils. In order to further improve the precision of the construction, thus the stability against discharges, a new technological solution for the production of the resistive layers has been introduced making use of copper clad DLC foils. This technique has been named Sequential Build Up (SBU) [7].

All the prototypes have been extensively tested [8-11] by mean of high intensity X-ray, muon and pion sources. Their performance have been compared in similar conditions: the Ar/CO_2 gas mixture (with proportion 93/7) was chosen to be on the safe side to minimise ageing effects (it is possibly not the best choice and can be optimised); the reference gain of the detectors was approximately 7000.

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The Pad-patterned detector (PAD-P) shows a quite significant charging-up for rates higher than ~100 kHz/cm^2 that nevertheless saturate at $\mathcal{O}$(1 MHz/cm^2) with a gain drop of about 20% at 20 MHz/cm^2. Its gain drop is limited to ~30% at a rate up to 100 MHz/cm^2. It shows no dependence on the irradiated area. It can be operated in very stable conditions up to gains larger than 10^4. It shows acceptable performance on energy (~48% FWHM/Peak) and spatial (200 μm) resolution. Among the detectors implementing DLC based resistive scheme best performance has been obtained with a surface resistivity of about 20 MΩ/□ and a pitch of grounding vias network of 6 mm. For this detector the gain reduction with rates is dominated by ohmic voltage drop, with a reduction ~20% at 20 MHz/cm^2 when irradiated on a 1 cm spot. It drops further to about 50% at 100 MHz/cm^2. The gain drop also depends on the irradiated area, causing a further 10% of gain loss at 20 MHz/cm^2, with an effect that saturates for surfaces larger than few cm^2. The DLC series have shown excellent performance in terms of energy (~30% FWHM/Peak) and spatial (<100 μm) resolutions. Their stability and robustness of operation (in particular under high rates) is not yet at the level of PAD-P. The DLC-SBU technique is promising but not yet conclusive. More extensive ageing tests and measurements with high ionizing particles will be carried in next future to complete the characterization of the spark resistive protection layouts.

An important part of our R&D project is to design and build a large size (~0.5 m^2) Small-Pad resistive Micromegas with fully integrated electronics on the readout board, with high channels density readout chips wire-bonded on the back of the anode plane. This approach will allow full scalability of the detector dimensions, avoiding any routing to external connectors. Resulting in a compact design, it allows to stack several detectors in a limited space for multi-gap/ multi-plane track measurements. This solution will also exploit the possibility of the construction of the full detectors with close to standard PCB techniques.

Possible future applications of Pixelated Resistive Micromegas are:

- Upgrades of experiments at present accelerators toward higher luminosity collisions. (Large Hadron Collider at CERN);
- Detectors for high energy (tens/hundreds TeV scale) and very high intensity new particle accelerators (FCC-ee/hh) or for the Electron-Ion-Collider (EIC);
- Large area fine tracking and trigger with high rate capability;
- Forward Muon tagging detector (e.g. ATLAS High Eta Muon tagger);
- Pre-shower for an electromagnetic calorimeter;
- Readout layer of a Time Projection Chamber.

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