Resistive microstrip and microdot detectors: a novel approach in developing spark protected micropattern detectors

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Abstract

Two new designs of micropattern gaseous detectors with resistive electrodes are introduced: the microdot –microhole detector and the microgap-microstrip-RPC. These novel detectors have several important advantages over the conventional micropattern detectors with metallic electrodes like GEM and MICROMEGAS. For example, the proposed detectors feature higher values of maximum achievable gas gains, a simpler layout with fewer components, a simpler production technique and cost effectiveness. Our studies have revealed many interesting features of such detectors: for example, adopting proper gas mixtures, the microdot detector can operate in self quenched streamer mode and at higher voltages in streamer mode similarly to RPCs.
These resistive microstrip/microdot detectors can be used in many applications, like noble liquid dual phase TPCs, TOF-PET, high time resolution muon trackers and so on.

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1. Introduction

Micropattern gaseous detectors (microstrip detectors, MICOMEGAS, GEM and others) offer unprecedented 2D position resolution (20-40 μm) making them very attractive for many applications like: tracking of charged particles, detection and visualization of X-rays and UV photons. However, owing to the fine structure of their electrodes, micropattern sensors can be easily damaged by sparks, which are almost unavoidable under real experimental conditions. The sparks appear when the total charge in the avalanche approaches the critical value Q_{crit}, typically 10^6-10^7 electrons, depending on the specific design of the detector. In some cases, however, at total charge values in the avalanche $Q_s<Q_{crit}$, surface streamers may form along the dielectric surfaces between the anode and the cathode electrodes that may trigger harmful discharges [1]. Usually surface streamers appear if the field lines are parallel to the dielectric surface along the whole surface between the anode and the cathode electrodes.
At the last three RPC conferences [2-4] we reported that the resistive electrode approach, used in RPCs, can be successfully applied to micropattern gaseous detectors making them spark-protected. Our first spark-protected detectors - GEM and MICROMEGAS - had unsegmented resistive electrodes [2, 4]. Later we focused on development of sensors with segmented (strips) resistive electrodes (see for example [5]).This approach turned out to be very fruitful allowing the development of various designs of large-area spark-protected micropattern detectors tailored to different applications (see [6] and references therein). For instance, recently, MICROMEGAS with resistive anode strips were developed for the ATLAS forward wheel upgrade (R-MICROMEGAS) [7].
In this paper, we will present two new designs of resistive microstrip detectors: the Microdot–Microhole Detector (RMMD) and the Microgap-Microstrips-RPC (MMRPC). These innovative micropattern spark-protected detectors are primarily oriented on applications in which some members of our team are deeply involved: noble liquid TPCs and TOF-PET and X-ray imaging [6, 8, 9].

2. Construction materials and methods

The RMMD was manufactured from a standard multilayer PCB board. The top layer of the PCB was covered by a 35μm thick Cu layer, the inner layer of the PCB board contained Cu strips 100μm wide at 1mm pitch (see Fig. 1a). On the top, a Cu layer of the PCB board, parallel grooves, 100 μm wide, were created by photolithographic techniques (fig. 1b). Subsequently, the grooves were filled with resistive paste ELECTRA polymers (Fig.1c). Then the residual Cu strips on the top of the PCB were chemically etched (Fig. 1d) and the entire top surface was covered (laminated) with a DuPont Coverlay film. Part of the Coverlay layer was photochemically removed creating open dots. The Coverlay covers only the edges of the anode dots (diameter of 25 μm) and the edges of the cathode strips (fig 1e). The thickness of the Coverlay layer on the top of resistive electrodes was 50μm. Finally holes of 0.3 mm in diameter were drilled along the resistive cathode strips by a CNC machine (fig 1f).

The principle of operation of the RMMD is similar to the so-called microstrip-microhole detector with Cu electrodes [10]: primary electrons created by charged particles or by X-ray photons in the drift region move under the influence of the electric field to the holes and, after passing the holes, drift to the anode dots where they experience the avalanche multiplication [10]. This geometry allows an efficient suppression of photon and ion feedback [10]. Therefore, RMMDs are optimal for applications like photodetectors or TPCs. RMMDs have two important advantages over the original microhole detector [10]: 1) spark resistance, 2) the Coverlay structure prevents the appearance of surface streamers allowing high gas gains to be achieved, limited only by the value of Q_{crit} thus achieving: $A_m=Q_{ctrit}/n_0$, where A_m is the maximum achievable gas gain and n_0 is the number of primary electrons created in the detector's drift region by the radiation. High gas gains are essential in the case of the noble liquid TPC aiming to detect several primary electrons.

The manufacturing procedure of the MMRPC is shown in figure 2. The first four steps a) to d) were very similar to the case of the RMMD described above: resistive strips with a pitch of 0.5 or 0.25 mm (depending on the specific design) and having thickness of 35 μm were manufactured by combination of photolithography and screen printing techniques. The difference was only in the geometrical arrangement of the strips: each resistive strip had a pick up strip positioned below it and both strips have the same width. If necessary, the grooves between the resistive strips can be covered with a dielectric layer to make a smooth surface (step e). Using these plates, MMRPCs with various gap widths, *G*, were assembled: 0.5 mm, 0.18 mm and 0.118 mm. As spacers, either washers, placed in the detector corners, were used or pillars manufactured by a photolithographic technology similarly to the case of MICROMEGAS. Note that the electrodes of this detector are somehow similar to the anode plate of the R-MICROMEGAS, the main difference being that the cathode mesh is replaced by the cathode plate with resistive strips. This feature not only simplifies the manufacturing procedure, allowing to automatize it, but also offers the possibility to achieve, with proper gas mixtures, high position and high time resolutions at the same time, similar to some designs of timing RPC.

The detectors were tested using the experimental set up described in [6]. Tests were done in Ne, Ar and their mixtures with CO_2 at a total pressure of 1atm. The primary electrons in the detector volume were created using one of the following sources: ^{241}Am (alpha particles), ^{55}Fe (5.9 keV photons), X-ray gun, described in [6] or by an Hg UV lamp. If necessary, the gas chamber with the detector inside could be cooled to cryogenic temperatures to perform gas gain measurements at these conditions.

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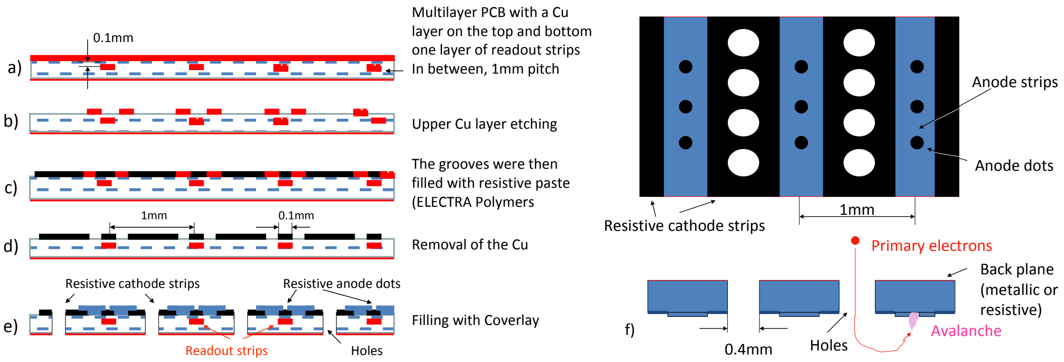

Fig. 1.Manufacturing procedure of a RMMD (a-e) and the technical drawing of the RMMD (f)

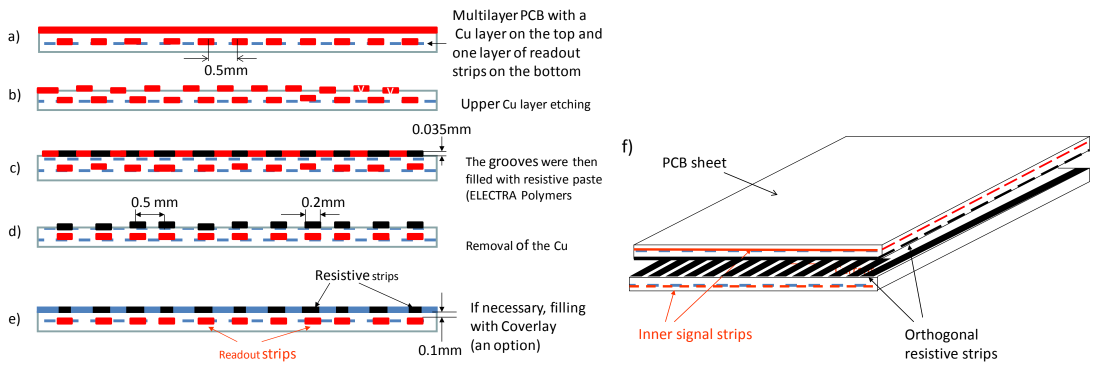

Fig. 2. Manufacturing steps (a-e) and an artistic view of the MMRPC (f)

3. Results

Figures 3a) and b) show the RMMD gain as a function of the overall voltage V_{ov} applied to the electrodes ($V_{ov} = V_{bc}+V_{ca}$, where V_{bc} is the voltage applied between the back plane and the cathode strips -the voltage across the holes- and V_{ca} is the voltage applied between the cathode strips and the anode dots) measured in Ne and Ar and in their mixtures with CO_2. In all these figures the filled symbols represent the measurements performed with alpha particles, whereas the open symbols refer to the results obtained with ^{55}Fe. Since with alpha particles one can observe signals even at a gas gain of one, the ^{241}Am source was very convenient for precise gain measurements at gas gains $\leq$100. At higher gains ^{55}Fe was used and the gain values were estimated from the measured avalanche charge and the known sensitivity of the amplifier. As it can be seen, in all these gases and mixtures at room temperature, the maximum achievable gain was ~3×10^4 to 2×10^5 which is 3-10 times higher than that achieved with other micropattern gaseous detectors operated with the same gases. Note that in Ar and its mixtures, at some critical total charge in the avalanche close to Q_{crit}, self quenched streamers appeared (see [11] and references therein). This is evidenced by a jump of one order of magnitude in gas gain, observed close to some critical gains. Visual observations revealed that they were formed near the anode dots and propagating towards the drift plane. A simulation was developed describing the formation and propagation of streamers in the case of the adopted geometry of the RMMD.
The same graph shows gain curves measured in Ne and Ar at cryogenic temperatures. Under cooling the maximum achievable gains drop. However, even at ~120 K gains are high enough to

detect several primary electrons which satisfy the requirements for noble liquid TPCs for dark matter searches. So far these are the highest gains achieved at cryogenic temperatures with a single-stage gas detector.

Fig. 4 shows the gas gain of the MMRPC measured both in current and pulse mode, in Ar+CO_2 gas mixtures. These mixtures were chosen in order to compare the gas gain of the MMRPC with the gas gains of other micropattern detectors, for example with R-MICROMEGAS (see [7]). Note that in contrast to RMMD, having a drift region, it is not straightforward to measure the gas gain in MMRPC, where no drift region is present. One way to measure the gas gain of the MMRPC is to let the radiation enter the detector volume at a well known distance from the anode and then exploiting the equation of the gas gain in the parallel-plate geometry, $A=exp(\alpha d)$, where α is the Townsend coefficient and d is the distance of the primary electron from the anode. The best way to measure A is to use the surface photoelectric effect from the cathode (in this case $d=G$) and perform measurements in current mode at low gains and in pulse mode at high gains. Alternatively it is possible to use a well collimated X-ray beam entering the detector volume close to the cathode and parallel to it. However, for technical reasons this can be used only when the gap is large enough, equal or greater than 0.5 mm. In this work we exploited both options. In the case of the measurements based on the photoelectric effect, we coated by a spray technique [12] the cathode plate of the MMRPC with a thin CsI layer. The UV beam of the Hg lamp was shooting inside the MMRPC almost parallel to its electrodes.

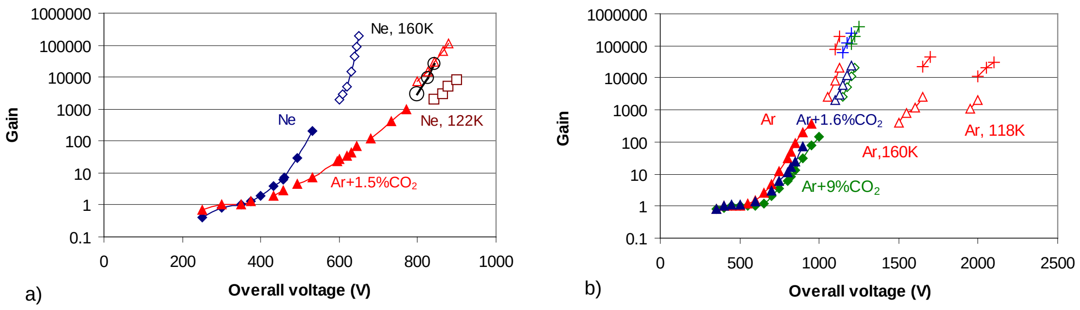

Fig. 3. Gas gain curves measured: a) in Ne and Ne+1.5%CO_2 and b) in Ar and Ar+CO_2 mixtures. Filled symbols–alpha particles, open symbols -^{55}Fe. Open circles and squares - gas gains measured in Ne at 160K and 122K respectively. Crosses in fig. 3b show the gas gains in self-quenched streamer mode at room temperature and at 160 and 118K.

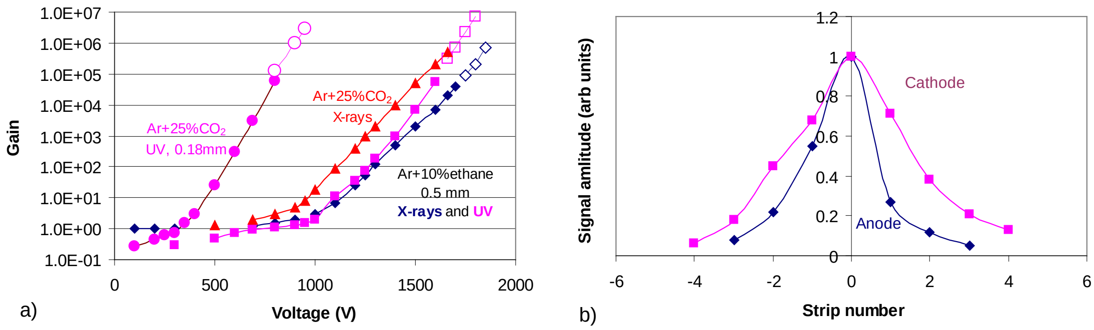

Fig.4. a) Gain vs. voltage curves measured with a MMRPC, having gaps G=0.18 mm (circles) and G=0.5 mm (triangles, squares and rhombuses) in current mode (filled symbols) and in pulse mode (open symbols), circles and squares-measurements with UV; b) Induced charge profile measured with collimated X-ray beam entering the MMRPC close to its cathode and parallel to it. Strips pitch is 250 µm

Fig. 4a shows gain curves as measured with a MMRPC both in current in the HV circuit (solid symbols) and in pulse mode - the signal induced on the readout electrodes (open symbols). In the case of G=0.5 mm, we performed measurements with UV and X-rays whereas at smaller gaps (G=0.18 and 0.118 mm) with UV only. As it can be seen, gas gains above 10^6 were achieved with all gaps. This is almost 100 times higher than with R-MICOMEGAS.
Fig. 4b depicts results of the measurements of the avalanche-induced charge profiles on the strips. As it can be seen, the FWHM of this distribution is about 0.5 mm. Note that earlier, with a different design of a narrow gap strip RPC oriented for medical applications, we have already achieved a position resolution of about 50 μm in digital mode. More accurately, the position resolution of the MMRPC will be measured during the oncoming test with charged particles beam during which we plan to use standard RPC gas mixtures (90% $C_2H_2F_4$ + 10%SF_6 or 90% $C_2H_4H_2$ + 5% SF_6 + 5%C_4H_{10}) in order to achieve at the same time a high position resolution and high time resolution, typical of small gap RPCs.

4. Conclusions

Novel micropattern detectors with resistive strip electrodes, introduced in this work, have several important advantages over the conventional micropattern detectors with metallic electrodes including GEM and MICROMEGAS. They feature higher values of the maximum achievable gas gain, a simpler design containing fewer components, a simpler production technique, allowing the implementation of automatic procedures, and therefore cost effectiveness.
As mentioned, RMMD can be used in advanced designs of dark-matter dual phase noble liquid TPCs combined with gaseous detectors [6] in which photomultipliers are replaced by a CsI photocathode or in which the noble liquid is doped with photosensitive additives, for example TMG [6]. For these particular designs, it is important to achieve as high as possible gas gain in pure Ar and Xe, needed for the detection of several primary electrons with simultaneous efficient suppression of photon feedback. Preliminary tests described in this work indicate that the RMMD geometry is an excellent candidate.
MMRPC have the potential to achieve simultaneously high position and time resolutions. Therefore, it is very well suited for applications as TOF PET, X-rays imaging and muon detection with high position and time resolutions and hence, can be an interesting alternative to R- MICROMEGAS and other micropattern detectors having limited time resolution (typically a few ns [13]) due to the presence of drift regions in these designs.

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