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Recent developments on Micro-Pattern Gaseous Detectors

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Summary. — Micro-Pattern Gaseous Detectors are nowadays well-established technologies and the application ranges from high-energy physics experiments (COMPASS, TOTEM, LHCb as few examples) to astrophysics, neutron detection, medical imaging. The interest and the R&D activities have increased in the last years, leading to new structures with new geometries and the development of larger-area detectors, suitable for the instrumentation of a large portion of the next generation SLHC or linear collider experimental apparatus. An international collaboration, RD51, involving over 50 institutes all around the world, was born to allow an easier exchange of information and to optimise the efforts and the resources for the development, the production and the characterisation of such detectors. An overview of the current activities is presented, reporting the latest results in this framework and their applications.

PACS `29.40.Cs` – Gas-filled counters: ionization chambers, proportional, and avalanche counters.
PACS `29.40.Gx` – Tracking and position-sensitive detectors.

1. – Introduction

The first Micro-Pattern Gaseous Detector (MPGD) has been the Micro-Strip Gas Chamber introduced by A. Oed in 1988 [1]. A set of micro-metric metallic strips, alternatively working as anodes and cathodes, are deposited over an insulating substrate exploiting standard photo-lithographic technology. The gas volume is enclosed by a further cathodic plane in front of them, allowing to define the drift field that drives the primary electrons to the multiplication region close to the anodic strips.

The new detector achieved a remarkable improvement in terms of spatial resolution and rate capability [2] with respect to the wire chamber technologies; on the other hand, it demonstrated significant vulnerability in the event of discharge, that could even lead to permanent damages to the strips structure [3], making it not suitable for environments

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with a highly ionising particles background. Eventually the problem has been solved introducing resistive substrates or by means of the edges passivation [4].

At the same time, a whole family of MPGD were invented, all of them characterised by photo-lithographic technology as production process: Micro-Groove Chambers [5], Micro-Wire Chambers [6], Micro-Pixel Chambers [7], Micro-Pin Array Chambers [8], Field Gradient Lattice Detectors [9] and the widely diffused Gas Electron Multiplier (GEM) detectors, introduced by Sauli [10], as well as Micro-Mesh Gaseous Structure (Micromegas) detectors, introduced by Giomataris [11].

GEM and Micromegas are nowadays well-established technologies, as proved by several years of operation in COMPASS experiment, the first high-luminosity experiment adopting them as high-rate tracking devices [12,13]; moreover, GEM detectors have taken part in LHC programme inside TOTEM experiment [14] and LHCb experiment [15], in the latter used as trigger device.

2. – Towards large-area MPGD

The SLHC upgrade and the future linear colliders are strongly demanding in terms of rate capability, time and spatial resolution, ageing properties. MPGD are a valid replacement for technologies that cannot fulfil all the requirements, but, for the instrumentation of large portion of these experimental apparatus, a consistent R&D effort in the direction of large quantities production of large-area MPGD is required.

In the framework of GEM detectors, two technological developments are quite promising: the single mask production technique and the GEM foils splicing [16]. The production of standard GEM foils is performed using two masks during the photo-resist exposure of the raw material, that is a copper-clad polyimide foil; the etching of the copper, as well as the following etching of the polyimide, acts on both faces of the foil at the same time, giving the typical bi-conical shape to the holes. For large foil production a very precise alignment of the two masks is not possible, but similar performances are obtained with the single mask production technique: in this case the etching proceeds from one face of the raw material to the other, giving rise to a conical shape of the holes. A fine tuning of the etching chemistry allows to obtain different angles of the conical shape, even very close to a cylindrical shape. In the same work the possibility to splice together several GEM foils is demonstrated too: a large prototype (circular sector shaped, with a size of about 60 cm × 60 cm) has been built exploiting these two techniques and its characterisation has been performed.

In the framework of Micromegas detectors, the bulk technology allows the production of the whole sensitive detector in a single process [17]: the anode plane with the readout structure, the photo-imageable material and the woven mesh are laminated together forming a single object. The chemical treatment creates the support pillars for the mesh removing the photo-imageable material. Several prototypes, built for the T2K TPC [18], exhibit a challenging uniformity of gain all over the detector surface, including corners, due to the enhanced control of the gap size obtained with this production process. The technology opens the way for the industrialisation of detector production and for the production of large-area Micromegas.

Such R&D efforts involve also other MPGD technologies. The Thick GEM (THGEM) is a hole-type structure, similar to GEM, realised by means of mechanical drilling, instead of chemical etching, of standard PCB [19-22], obtaining a robust and self-supporting layer. The production process can be easily transferred to the industry, and recently

$60 \times 60\,\mathrm{cm}^2$ prototypes have been realised [23] in the framework of the COMPASS RICH photodetectors upgrade.

3. – Recent developments and applications

Applications of MPGD have continuously increased in the last years, ranging from high-energy physics experiments to astrophysics, photon detection, neutron detection, medical imaging, and in this section we are providing just a not exhaustive list of examples.

The GEM technology demonstrated the possibility of the instrumentation of curved surfaces. Semi-cylindrical GEM detector prototypes have been realised at CERN [24] and a full cylindrical detector is under construction in the framework of KLOE experiment upgrade [25], where it will be used as inner tracker with very low material budget. Eventually, the proof of principle of a semi-spherical GEM foil, obtained as a deformation at high temperature of a planar foil, has been demonstrated at CERN [26] and further R&D is ongoing.

The hole-type amplification structure is quite interesting for gaseous photodetectors equipped with photoconversion layers such as CsI. THGEM with a CsI deposit on top surface has been investigated by several groups for many years [19-22]. With respect to wire chambers with CsI on the cathode, the closed geometry of the holes avoids that photons emitted in the avalanche reach the CsI layer, strongly reducing the photon feedback. We have already mentioned in the previous section the THGEM photodetectors for COMPASS RICH upgrade: the challenge in this case is not only the large-area coverage, but also the very high photon detection efficiency required for the reconstruction of Cherenkov rings [27].

The introduction of resistive substrates in MPGD can bring several advantages. In Micromegas with charge dispersive readout [28] the readout electrode is a resistive layer capacitively coupled with strips or pads. The charge is spread over several strips and the charge centre of gravity technique allows to obtain competitive spatial resolution of the order of $50\,\mu\mathrm{m}$ while keeping small the number of electronics channels. Moreover the resistive layer is a protection for the electronics in an event of discharge.

In the Resistive THGEM (RETGEM) the resistive layers over the THGEM faces lead to the reduction of discharge probability. Recent measurements [29] in the framework of photodetection demonstrate that gains of the order of 10^6 are obtained with neon-based gas mixtures.

An interesting approach is the integration of the MPGD with a CMOS pixel readout chip [30-35]. The small-size pixels typically exhibit very low noise levels, allowing single primary electron detection even at a moderate gain of few thousands. A recent development is the production of the Micromegas amplification structure over the CMOS chip by means of the “wafer post-processing” technique [36]: a thin ($1\,\mu\mathrm{m}$) aluminium grid (InGrid) is fabricated on top of an array of insulating (SU-8) pillars ($50\,\mu\mathrm{m}$ height) standing above the CMOS chip.

4. – RD51 Collaboration

Concluding this review, we report that the MPGD community has converged in the RD51 Collaboration [37], with the aim of sharing information, results and experiences, and steering R&D efforts. About 350 authors from 57 institutes in 20 countries worldwide have signed the proposal, approved by CERN at the end of 2008.

The collaboration does not focus on one or a few particular applications for MPGD, but is rather technology oriented. Participating institutes will take advantage of the sharing of the resources, the creation of common projects and the realisation of common infrastructure for production and test.

The activity is divided in seven working groups, with a number of tasks assigned to each of them. WG1 focuses on MPGD technologies, for the design of new structures and geometries and the development of large-area MPGD. WG2 discusses physics issues related to MPGD, such as discharge, dielectric charging up, ageing; it aims also to define common test standards for the comparison of measurements of different groups. WG3 concentrates on the specific applications and studies the optimisation aspects connected to the specific requirements. WG4 studies gaseous detector simulation and takes care of the simulation software tools development. WG5 develops the Front-End Electronics and the Data Acquisition systems for the collaboration. WG6 is concerned by production issues, coordinating the upgrade of production facilities and the technology transfer to industrial partners. WG7 is devoted to common test and irradiation facilities, including the organisation of a semi-permanent test beam set-up at CERN.

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