MICROPATTERN GASEOUS DETECTORS — NEW DEVELOPMENTS AND APPLICATIONS

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In recent years, there has been rapid research and development in the field of MicroPattern Gaseous Detectors (MPGDs). A variety of new applications have been implemented in many scientific disciplines, where the advantages of MPGD technology play a really important role. In this paper, a brief description of the evolution of MPGDs is presented, with particular focus on large projects and imaging applications.

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1. Introduction

In recent years, rapid developments have taken place in the field of gaseous detectors. The scope which is covered by these research and development projects is broad and includes photon, charged particle and neutron detection. Moreover, traditional multi-wire and parallel plate types of gaseous detectors, which have been widely used in high energy physics (HEP) experiments up till now, have currently sufficiently mature competitors: MicroPattern Gaseous Detectors (MPGDs). The fields of application for a variety of MPGD types have become increasingly broad in recent years, and encompass areas which are far from HEP — even though most MPGD research projects have been driven by the latter. Most of the work done by many groups all over the world is linked by the CERN RD51 program and the collaboration which is built around those projects [1].

The main focus of this paper is to present selected aspects of recent MPGD developments, which were presented by the author during the Jagiellonian Symposium on Fundamental and Applied Subatomic Physics in Kraków, June 7–13, 2015. In particular, an upgrade program for the main Large Hadron Collider (LHC) experiments and selected imaging applications based on MPGDs will be discussed in greater detail.

2. A brief history of MPGDs

The first MPGD was proposed by Oed [2], who considered using already well-developed microelectronics production technology in the manufacturing of a gaseous type of detector. It was thought that employing well-optimized microelectronics technology could lead to a simplification of detector production, which at that time was quite a complicated and expensive task (due to wire stretching and positioning). Other important benefits which were immediately gained were better spatial resolution and reduction of costs in mass production.

In his work, Oed proposed a micro-anode structure similar to that of wires, deposited directly on an insulating layer (*e.g.* glass). That is how the very first MPGD detector, called a Micro-Strip Gas Chamber (MSGC), came into existence. The layout of the electrodes allowed the creation of a high electric field in most of the region in between the amplification stage electrodes, leading to a faster detector response, higher counting rate capabilities and sub-millimeter spatial resolution. This first attempt at production of a micro-type of gaseous detector was very successful; however, there were some drawbacks. Namely, a quite high probability of discharges caused by a high electric field in most of the region between the strips, resulting in damage to the tiny electrodes. Another important aspect was ageing effects, caused by deposition of impurities on the surface of the tiny strips. Nevertheless, this design (with minor modifications, largely solving the mentioned problems) has been successfully used up till now. More importantly, this development paved the way for the construction of a variety of new micro-type gaseous detectors. In general, all detector types which have high granularity elements with a tiny distance between electrodes (less than 1 mm) are considered MPGD detectors.

Among many other developments, one has to point out the two most important MPGD types: the Micro-Mesh Gaseous Structure (MicroMEGAS) — introduced in 1996 [3], and the Gas Electron Multiplier (GEM) — constructed for the first time in 1997 by Sauli [4]. The MicroMEGAS detectors have a uniform field amplification stage (quite similar to the old parallel plate counters), while in GEMs, the drift, transfer and induction regions are completely separated, making those features quite unique in MPGDs. They immediately bring advantages such as fast ion evacuation — therefore, the amplification stage is much less affected by the space charge of slowly moving ions. More information about MicroMEGAS can be found in [5].

A standard GEM detector is made up of a drift cathode, two or more GEM foils, and a readout structure. The GEM structure consists of a thin, metal-clad polymer foil chemically perforated with a high density of holes. The holes typically have a density of about 10 mm^{-2} and a diameter of less than 100 μm. The gas amplification region is localized inside the holes, where the electric field strength is high enough to let the electrons create secondary electron–ion pairs. Usage of more than one foil significantly reduces discharge probability, keeping total gas gain at the same, high level [6]. The GEM detector has another very unique feature — full decoupling of the charge amplification structure(-s) from the charge collection and readout structure. Therefore, both structures can be optimized independently and adequately for a given application. One more interesting and very encouraging aspect directly related to the GEM foils is the possibility of making detectors of a variety of 2D shapes or even cylindrical ones (*e.g.* TOTEM [7] or NA49 future experiments at CERN). The GEM detectors are also less sensitive to ageing than other MPGDs [8]. There are somewhat similar detectors based on the same idea, known as Thick GEMs. The main difference is that instead of foils, standard printed circuit boards (PCBs) are used. The PCBs are thicker than foils and are perforated with larger holes with a lower density; however, the principle of operation is the same as for GEMs. Thick GEMs are much cheaper than (ordinary) GEMs and can be produced with standard PCB technology without almost any sophisticated post-processing. They are very suitable in areas where their moderate position resolution (about 1 mm) is sufficient, and high gas gain with spark resistance are required combined with relatively low costs of production [9].

There are more (but less frequently used) variety of MPGDs such as: MicroPin [10], MicroWELL [11], MicroGroove [12], μPIC [13], Micro-Hole-and-Strip Plate (MHSP) [14] and others; however, a description of these detectors is beyond the scope of this article.

3. Selected MPGD applications

3.1. Recent projects in the field of HEP

Currently, one of the main areas of application for MPGDs is the muon spectrometer upgrade program for the ATLAS experiment [15]. The detectors will cover an area as large as 150 m^2 and will be a part of the New Small Wheels of the ATLAS Endcap Muon tracking system. MicroMEGAS detectors have very good space resolution and are capable of handling a high rate, which together with their reliability make them an excellent choice for the upgrade. For the first time, MicroMEGAS detectors will be used in an HEP experiment on such a large scale.

A fairly similar approach has been undertaken in the upgrade of the forward muon system of the CMS experiment at CERN [16]. In this case, triple GEM detectors have been selected. Similarly, they have an excellent rate performance combined with a high spatial resolution, which provide excellent capabilities for triggering and tracking. The upgrade will improve triggering efficiency for the muon forward region by trigger rate reduction due to better discrimination of high transverse momentum muons.

3.2. Imaging application

Rapid development of MPGDs is also noticeable in the field of imaging applications. Interesting applications include: homeland security and the imaging of high-Z materials based on muon tomography equipped with GEM detectors [17]. The idea is to use large area GEM detectors to identify the scattering of cosmic ray muons (especially in high-Z materials) to make tomographic images of the investigated volume. Results obtained so far are promising and can give useful information about hidden high-Z materials inside scanned objects. However, in this case (and many others), lack of appropriate, fast and comprehensive electronic readouts is a limiting factor.

In the field of medical imaging, systems based on MPGDs are also starting to be used. One example is the Proton Range Radiography (PRR) system used to measure the residual energy of a proton beam traversing an absorber and create a two-dimensional (2D) map of the integrated density in the target. In this case, a pair of triple 30×30 cm^2 GEMs has been chosen for tracking, because of their high sub-millimeter spatial resolution and excellent rate capability. The GEMs together with a stack of scintillators produce proton transmission radiographic images by measuring the residual range of the protons leaving the patient [18].

4. MPGD related developments in AGH UST

Recently, efforts have been made to overcome the problem of inappropriate readout electronics. The only solution directly dedicated to gaseous MPGD detectors already existing with proven comprehensive functionality is a system based on: the MSGCROC and its successor GEMROC [19] front-end application specific integrated circuits (ASICs) equipped with Ethernet, and the Field-Programmable Gate Array (FPGA) dedicated data acquisition system (DAQ) developed at AGH UST [20, 21].

In the field of neutron detection, MPGD detectors are also available. Their development is related to the advent of pulsed spallation neutron sources driven by proton accelerators, such as the Super Neutron Source (SNS) in the USA, J-PARC in Japan, and — expected to be launched in 2019 — the European Spallation Source (ESS). To cope with high neutron fluxes, detectors with high counting rates capabilities and much improved spatial resolution are required. For example, a low pressure MSGC with a solid state neutron converter is one of the options (developed in cooperation with Helmholtz-Zentrum Berlin). It uses a $^{\mathrm{nat}}$Gd/CsI converter to capture (epi-)thermal neutrons and release a detectable cluster of electrons. Liberated electrons are multiplied inside the MSGC detector and generate signals in a 2D readout structure directly connected to DAQ. Without going into detail, the system can withstand high neutron flux and is capable of capturing detailed images as presented in figure 1 [22].

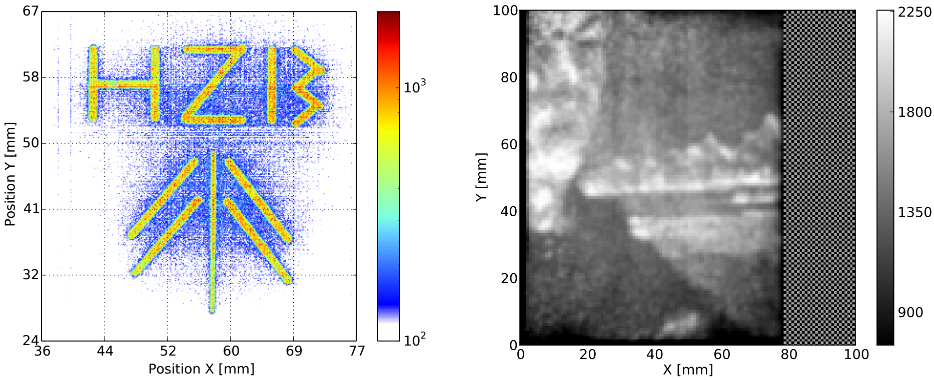

Fig. 1. Image obtained with thermal neutrons and an MSGC detector (left) [22]; XRF photon image of painting recorded with a triple GEM detector (right) [23].

Another very rapidly growing field is imaging applications in art, especially painting, but not exclusively so (other examples include stained glass, parchment and small sculptures). When studying cultural heritage, non-destructive methods are very often necessary to discover the origin of an object or uncover the hidden composition of a painting. Two commonly used methods, among many others, are X-ray radiography (XRR) and X-ray fluorescence (XRF). In this area, MPGDs are also starting to play an important role, especially when a rapid and safe investigation of a valuable object is essential. For example, an XRF imaging system for the mapping of pigment distributions in paintings based on a triple GEM detector, a pin-hole camera and dedicated DAQ electronics has recently been presented in [23]. The overall system has been optimized for this particular application, resulting in fast, energy dispersive XRF photon detection, providing 2D maps of pigment distributions (see example results shown in figure 1). Moreover, due to its robustness, the system can easily be rearranged to obtain 2D radiography maps of high-Z elements present in a painting. A fairly similar approach to imaging of parchments has also been presented in [24].

5. Conclusions

As very briefly presented in this paper, MPGDs are used in a broad range of fields, and, moreover — due to rapid growth — this range is becoming even broader. These successes definitely show that MPGD is already a sufficiently mature technology, with many areas where it can be applied effectively. To recap a few of them: the large area detection systems used for tracking and triggering in the upgrade programs of the main LHC experiments, a variety of imaging applications (neutron, proton and X-ray), homeland security, and even medical applications. However, it should be pointed out that this rapid progress in MPGD development would not have been possible without the combined efforts of many scientists working together under the RD51 Collaboration.

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