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Dzhelepov Laboratory of Nuclear Problems

FINAL REPORT ON THE SUMMER STUDENT PROGRAMME

Production of Micromegas detector at JINR

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Abstract

In recent times the study of Quantum Chromodynamics (QCD) has produced a large variety of outstanding experimental and theoretical achievements, a remarkable contribution to the comprehension of the nature of matter. However the picture it provides is still incomplete: many questions, in fact, have found no answer yet. The proposed experimental facility COMPASS++/AMBER aims at giving its contribution in seeking answers to unsolved problems. COMPASS++/AMBER collaboration proposes measurements at M2 beam line of the CERN SPS, using the already existing COMPASS spectrometer with major upgrades in the detector setup. Among the upgrades, the replacement of MWPCs with an MPGD-based large area tracking system is under study at Torino University laboratories. Currently, a Micromegas-based solution is being studied in collaboration with DLNP at JINR, where production and part of the tests of the prototypes is carried out.

This report describes in detail the fabrication process of the Micromegas prototypes at DLNP at JINR.

1 Introduction

The study of Quantum Chromodynamics (QCD) is crucial since it links the dynamics of fundamental particles, such as quarks and gluons, to properties of hadrons like nucleons and nuclei. Over the last four decades, restless investigation in this vast field lead to outstanding results which brought to the consolidation of QCD as the main theory for describing the behaviour of matter around us. Despite remarkable efforts have been made both by experimental and theoretical physicists all over the world, still some questions have found no answer. In this fertile ground, the proposed experimental facility COMPASS++/AMBER [1, 2] aims at giving its contribution in seeking answers to unsolved problems such as, for example, precisely measuring the proton radius, determining the widely unknown parton distribution functions (PDFs) of the pion or performing high-precision spectroscopy of the strange-meson spectrum. Many physics programmes proposed in the frame of the new born COMPASS++/AMBER collaboration are based on the concept of using the present COMPASS setup [3]; however, major upgrades of the spectrometer are required.
In the context of a general upgrade of the detectors, Multi-Wire Proportional Chambers (MWPCs), currently used for large area tracking along the whole spectrometer, need to be replaced because of aging. A cost-effective solution for covering large surfaces is given by newly developed Micro Pattern Gaseous Detector (MPGDs). The name MPGD refers to a family of gaseous detectors characterized by micrometric distance between electrodes (hence the name); the fabrication process exploits techniques developed for electronics industry, such as circuit printing, allowing to keep the production costs low. Among the most widely used MPGDs, Micromegas have been proposed for replacing COMPASS MWPCs.
COMPASS MWPCs replacement is under study at Torino University and Micromegas prototypes are designed, produced and tested. DLNP at JINR is collaborating with Torino University in the prototype fabrication.

2 Gaseous detectors

The working principle of most gaseous detectors is ionization [4]: incoming radiation ionizes gas atoms (or molecules), creating electron-ion pairs. If a voltage difference is applied, electrons and ions do not recombine, rather they drift in opposite directions. During their drift electrons can acquire sufficient energy to further ionize the gas, giving birth to an "avalanche" charge multiplication. This net movement of charges induces, on proper readout electrodes, and electric signal that can be registered and recorded.

The filling gas mixture in a ionization-based gaseous detector must meet some requirements, such as allowing high gains, low operating voltage, high rate capability. Operation at low voltages is addressed by choosing noble gases as main components of the mixture; among noble gases argon is often chosen. However in pure argon high gains can not be obtained: high energy excited states yield high energy γ which may induce discharges. In order to increase the gain, hence, it is necessary to add a *quencher*, a gas, such as CO_2, for instance, which can absorb γ in non radiative processes. In order to further increase the gain it is possible to add a small amount of an electronegative gas, which can absorb γ and e^-.
Gaseous detectors have been intensively studied and produced because of the several advantages they provide. Nowadays, in order to meet different requirements in very different applications, a wide range of geometries has been studied and implemented.

2.1 Micro-Pattern Gaseous Detectors

A wide class of detectors is grouped under the name *Micro-Pattern Gaseous Detectors*, shortened in MPGD, that includes strips, dots and holes -type structures. Hence, it can be useful to point out the common characteristics of this "family": they are high granularity[1] gaseous detectors with small (below 1 mm) distance between the anode and the cathode electrodes. Among the main advantages of MPGDs, microelectronics technology based fabrication process keeps manufacturing costs relatively low, providing a cost-effective detector. Moreover, the easily achievable high granularity offers potentials for very high position resolutions. Finally, the small distance between anode and cathode electrons enhance fast ion collection, giving way to good counting rate capabilities.

2.2 Micromegas

MicroMesh Gaseous Structures, or Micromegas, are a new generation of detectors developed from the '90s at Saclay by Y. Giomataris and G. Charpak [5, 6, 7]. A Micromegas detector can be thought of as two successive parallel plate counters separated by a thin metal mesh, hence the name Micromegas, which works as an electrode for the both of them. The first one, called *conversion* or *drift region* has a typical electric field of $\sim 1\ kV/cm$, and the gap between the electrodes is of the order of few millimeters. In this gap, incoming radiation ionizes the atoms of the gas and the electron ion pairs so produced drift towards the electrodes. While ions are collected at the surface of the

[1] or, at least, high granularity is easy to achieve

cathode, electrons drift through the mesh. Just crossed the mesh electrons get into a high electric field region, the so-called *amplification region*, where avalanche multiplication occurs. The electron cloud drifts till the anode, while the ions produced in the avalanche are collected by the micro-mesh. In the amplification region the electric field has typically high values, $\sim$ tens of kV/cm, in order to ensure charge multiplication. Typical amplification gap values are of the order of hundreds of μm; this thin distance is kept constant by using insulating pillars, deposited by standard photolithographic method. The electronic readout can be performed using arbitrarily segmented anodes. Modern technologies developed for printed circuits allow to print micrometrically spaced and arbitrarily shaped electrodes, such as strips or pixels. Different anode pattern are possible in the same detector, allowing different rate capabilities to different sections of the detector.

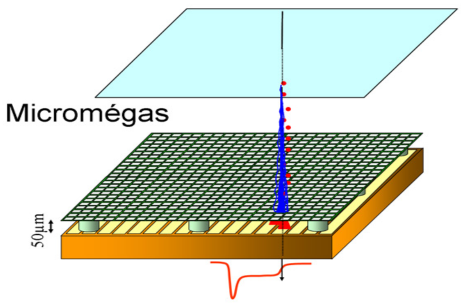

Figure 1: Schematic of a Micromegas detector. Conversion region (where primary ionization occurs) and amplification region (where multiplication occurs) are clearly visible

A standard technology for suspending the mesh above the anode consists in laminating a photoresistive film of the desired thickness and the mesh together at high temperature; by photolithographic method, then, the photoresistive material is etched producing the pillars. Detectors built using this technology are called *bulk* Micromegas. In many applications it is required to cover large surfaces with detectors, hence, bulk technology may become challenging. In fact it requires either to laminate all the surface at once – which may be impossible - or to split the surface in smaller blocks and laminate them separately. The second option, however, in order to avoid non uniformities in the electric field, implies to achieve an extremely precise match in assembling, both between anode planes and between meshes which in most cases is impossible to obtain. A possible solution is to laminate only the photoresistive material and carve the pillars; the mesh, which is unique for the entire detector surface, is then stretched on a support frame and is laid above the pillars. This type of detector is called *floating mesh* Micromegas.

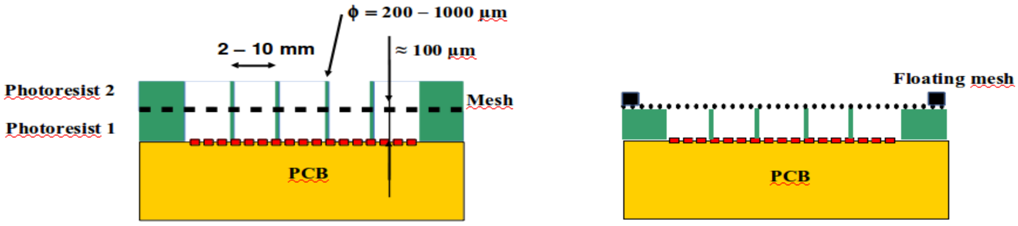

Figure 2: Difference between a *bulk* Micromegas a *floating mesh* Micromegas

3 Fabrication

One of the major advantages of Micro Pattern Gaseous Detectors is the industrial production of many components of the detector, which provides a cost-effective solution in many applications, especially when large sensitive surfaces are required. Readout anodes, for example, are often printed on fiberglass with standard industrial technique, reaching high precision at affordable prices. In our prototypes also high voltage distribution lines are printed on fiberglass, while pillars for suspending the mesh are carved out of a photoresitive film, using UV lithography technique.
Fabrication of the prototypes is a multi stage process; at each step several parameters need to be chosen in order to optimize the final product. Parameters that need to be tuned are, for example, lamination temperature, UV exposure energy, definition of the cleaning procedure. A remarkable effort in fine tuning of such parameters has been made by A. Gongadze and D. Zavazyeva ([8] and non published works) in JINR DLNP, thus providing a fundamental *know how*.

Figure 3: Fabrication chain at JINR DLNP. From left stretching machine, oven, laminator, UV insulator, etching machine

3.1 Lamination of the photoresistive film

Whichever building technology is chosen (bulk or floating mesh), the first step is the lamination of the photoresistive layer on the detector PCB. After chemical etching, in fact, it will form the pillars needed for suspending the mesh. The used phototresistive film is DuPont Pyralux 1025. It is a negative phototresist, which means that UV exposed parts will eventually become resistant to the chemical solution and will not be washed away. Photoresistive film is 64 μm thick; higher anode – mesh distances can be obtained by laminating more than one layer. In particular, most of the prototypes in this R&D programme have a 128 μm amplification gap, which means a double phototresistive layer. In JINR DLNP a C SUN CSL – M25E laminating machine is available. In order to get a optimal lamination, machine parameters have been finely tuned, resulting in a sort of standardized procedure. Before lamination, the PCB is preheated at 50° C. During lamination process, lamination roller temperature is set at 100° C, while hold down roller temperature at 50° C; the pressure between the two rollers is set at 3 kg/cm^2. Lamination speed is set at 1 m/min.

Figure 4: Lamination of a prototype at JINR DLNP

3.2 Mesh stretching

The micrometric metal mesh suspended above the readout plane is the heart of a Micromegas detector. Careful attention should be paid in mesh stretching operation, since small non uniformities might cause charge accumulation and, subsequently, discharges. The mesh chosen for prototype fabrication is made of woven stainless steel 18 μm diameter wires spaced by 45 μm. A stretching machine is available in JINR DLNP. As mentioned in the previous sections, different Micromegas technologies require different strategies for assembling the mesh electrode. For *bulk* Micromegas production, the

mesh is stretched above a frame and glued with epoxy glue; measured tension must be around $10 \div 15\ N/cm$ in both dimensions. The mesh is then laminated on the photoresist and a final, single, photoresistive film is laminated on top of it. The mesh is hence embedded in photoresistive layers. After pillar carving the mesh is cut and soldered on the amplification voltage pad.
For *floating mesh* Micromegas production, instead, the mesh is glued on a metal frame with no needs for lamination; the mesh frame is eventually laid on top of the photolithographically carved pillars. However, some difficulties arise from the shape of the frame. In the *floating mesh* prototypes produced so far, the mesh frame has a flared cross section; mesh needs to be glued on the sloping side, in order to avoid possible non uniformities on the flat part due to a non uniform glue spreading. Hence mesh stretching requires a two-step process: mesh is first stretched and glued on a provisional frame, called *transfer frame*, with the help of the stretching machine. Later the mesh is glued on its proper frame using weights in order to let it perfectly adhere to the frame slope. Mesh is then cut and edges are polished with sandpaper, in order to prevent charge accumulation on spikes.

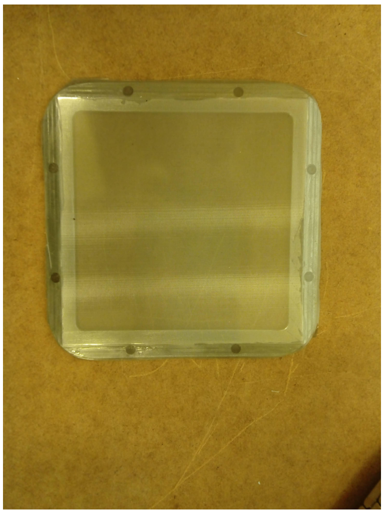

Figure 5: Mesh glued on its frame for a "floating mesh" prototype

3.3 UV exposure

As previously explained, photolitographic method for carving the pillars require a UV light exposure of the parts that will be resistant to the washing, i.e. the pillars themselves; a special mask is then needed. In JINR DLNP a C SUN UVE – M500 UV is available; it is equipped with a mercury vapour lamp. Power fine tuning has been a crucial step in technology development, since many problems may come from non

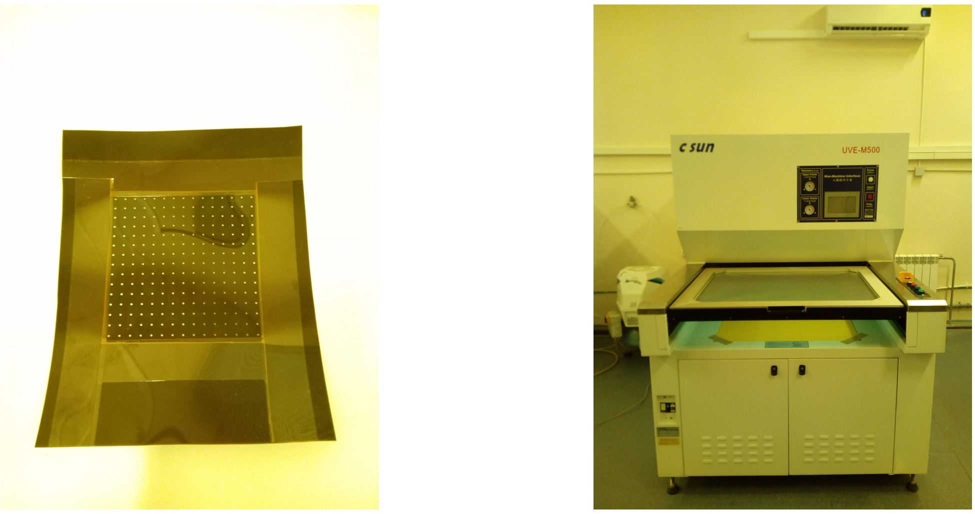

Figure 6: Left: mask used for pillar photolithography. Right:UV insulator.

uniform pillar shape. In fact, overexposure or underxposure of the photoresist film may lead to a non cylindrical shape of the pillars, enhancing dust accumulation. Chosen operating power is 0.2 mJ/cm^2 per layer, since it gives the best uniformity in pillar carving, according to microscope observation.

3.4 Chemical etching

A Bungard Sprint 3000 is used for etching of the non exposed photoresistive material with a 1 % Na_2CO_3 solution. Chemical etching parameters have been carefully chosen; in order to obtain the best etching, according to observations, washing temperature must be around $23° \div 24°\ C$ and the speed around $0.2 \div 0.4\ m/min$. Higher speeds or lower concentrations may cause the presence of non etched areas, while lower speeds or higher concentrations may leave overetched areas. In both cases uniformity in the shape and dimension of the pillars is not ensured, causing a possible dust accumulation, which might lead to electrical discharges in an operating detector. As the non exposed film is etched, the detector is washed with deionized water and dried at the temperature of $140°\ C$ for four hours to cure photoresistive material.

3.5 Cleaning

Even though cleaning should be a major issue at every step of the fabrication chain, it is almost impossible to avoid dust or dirt accumulation during the whole process. Hence, a final deep cleaning is necessary in order to avoid discharge or excessive current flowing once the detector is operating; obviously in case of *floating mesh* Micromegas both the PCB and the mesh must be cleaned. Cleaning procedure is the result of several years experience in detector fabrication. For the first cleaning a commercial detergent and warm tap water ($30^\circ \div 40^\circ\ C$) are used; in order to remove dust that may remain close to the pillars a brush is needed. Detergent is removed with tap water and then components are washed with high pressure ($30 \div 40\ atm$) deionized water[2]. After drying at $\sim 40^\circ\ C$, a final dry cleaning is carried out with a dust cleaning roller.

3.6 Drift electrode mounting

The raw detector structure is completed by adding the so-called *drift electrode*, the electrode used for establishing the correct electric field in the conversion gap. It is made of a metal mesh stretched and glued on a frame connected to the power supply.

3.7 Assembling

Final step towards a working prototype is the assembling. Assembling of a *bulk* prototype requires to suspend drift electrode on glued screws by spacers and fixing it with nuts. A *floating mesh* prototype, on the other hand, is slightly more complicated, requiring to fix mesh frame first and drift electrode later. Fixing the mesh frame does not require extreme precision since mesh adherence to pillars is ensured by the electrostatic attraction exerted by the anode once a voltage difference is applied. On the PCB detector core holes are dug for placing the screws; those holes link the outer part of the detector with its inner part, where gas need to be contained. They can, thus, pose a problem in gas-tightness of the detector itself. Hence, careful attention has been paid in gluing the screws, ensuring that an epoxy glue ring leaves no room for gas leakage.

4 Conclusions

In this report a general overview of the planned upgrade of COMPASS spectrometer has been presented, with a particular focus on the new MPGD-based large area tracking system.
The fabrication process of a Micromegas detector at DLNP at JINR has been described in details. Prototypes produced are hence ready for being tested both in DLNP and in Torino laboratories.

[2]a slightly lower pressure is required for the mesh, since it might be unglued from its frame

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Contents