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Progress on large area GEMs

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Recent developments on large area Gas Electron Multipliers (GEMs) will be presented.
In 2008, a triple GEM detector prototype with area of ˜2000 cm2 was built. GEMs of such dimensions had not been made before and innovations to the existing technology had to be introduced in order to build this detector. A manufacturing process based on a single mask photolithographic technique allowed overcoming the cumbersome practice of alignment of two masks, which limited the achievable lateral size. The GEM holes obtained in this way have a typical conical shape and present a so called rim, a small insulating clearance in the substrate around the hole.
Recent progresses allow a further refinement of the production method, giving greater control over the size of the rims and the dimensions of the holes. In this framework, simulation studies have been performed to investigate the effect of the hole shape on the behaviour of the GEM. Such studies can help understanding how to use the new enhancements to optimize the performance.
Many potential applications for large area GEMs foresee large production volumes. Production issues have been studied and single mask GEMs turn out to be more suitable for large scale production than standard GEMs.

Summary (Additional text describing your work. Can be pasted here or give an URL to a PDF document):

Many present and future applications of Micro Pattern Gas Detectors (MPGDs) in High Energy Physics as well as in other fields of research and applied science require large area coverage. However, until recent past, gas detectors based on Gas Electron Multipliers (GEMs) were limited to ˜50 cm linear size. An effort has been started to find a manufacturing technique that can be scaled up to square meter size.

In 2008, a prototype large area triple GEM chamber was made, aimed at an application in the TOTEM experiment, as an upgrade of its T1 tracker, currently a cathode strip wire chamber. The active area of this prototype is ˜2000 cm2 and the used GEM foils have linear extension of 66 cm. To produce foils of such dimensions, limitations in the standard fabrication procedure had to be overcome.

The production of standard GEM foils is based on the photolithographic process commonly employed in the printed circuit industry. The GEM hole pattern is transferred by UV exposure from flexible transparent films to a copper clad polyimide foil laminated with photo resistive material. One film is used to transfer a pattern on the GEM top and a second mask is used to transfer the pattern on the GEM bottom. After development, the foil can be etched in an acid liquid that removes copper from the holes, but not from where the photoresist still masks the copper. The next step is etching the polyimide substrate, for which the holes in the copper act as a mask. In order to obtain a homogeneous hole geometry across the foil, it is imperative to keep the alignment error of the top and bottom masks within 5-10 µm. As both the films and the base material are flexible, this alignment is far from trivial. If the detector linear dimensions exceed 50 cm, the alignment is hardly feasible anymore.

A way to overcome this problem is to use the single mask photolithographic technique, in which only one mask is used, removing in this way any need for alignment. In this case, the bottom copper layer is etched after the polyamide, using the holes in the insulating material as a mask. The quality and homogeneity of the holes depends now critically on the control of the polyamide etching, where mask alignment used to be the limiting factor. This manufacturing method had not been used in the past because it produced holes with low aspect ratio (defined as the ratio depth / width of the hole). Recent developments in the chemistry of polyamide etching open the way to the use of the single mask technique. Moreover, the introduction of a two-steps etching process can increase even more the aspect ratio and give higher control over the shape of the holes. The holes obtained in this way have a typical conical shape, which steepness can be tuned by changing the composition of the two etching solutions.

The single mask technique gives rise to the so called rim, a small insulating clearance in the substrate around the hole that can degrade the time stability of the gain due to dielectric surface charging. In order to minimize the rim width, it is possible to slim down the thickness of the copper electrodes before etching the holes. To avoid creating rims on the top electrode at all, one has to protect it while etching the bottom electrode. Experimental evidence shows that the electrochemical protection is the most suitable technology in this sense.

The GEMs produced with the single mask photolithographic process with electrochemical protection have a gain almost consistent with standard GEMs. However, they seem to be more easily damaged by discharges than other GEMs. Adding a rim of about 1 μm can solve this problem.

This new manufacturing technology introduces conical holes and gives large freedom on the control of the hole shape. Still, it is not yet obvious what would be the optimal shape of a hole, or the optimal orientation (larger diameter towards anode or cathode). To gain some knowledge on how the shape and orientation of GEM holes influence its properties, a simulation effort has been started. The simulation studies, based on the Garfield package, show the different behaviour of holes with various diameters on top and bottom.

Applications of large area GEMs range from forward tracking and triggering in sLHC experiments to barrel tracking with cylindrical GEMs, time projection chamber readout, digital hadron calorimetry for ILC experiments, cosmic muon tomography for homeland security and so on. Many of these applications foresee large production volumes and therefore some industrialization process is needed. Contrary to standard GEMs, single mask GEMs are particularly well suited for mass production. All steps in the fabrication process can in principle be done with roll-to-roll equipment, due to the absence of involving manual interventions. The maximum production rate is several thousand m2 per month, much greater than required for detector development. The price per unit area is expected to drop by almost two orders of magnitude compared to standard GEMs.

Authors: VILLA, Marco (CERN); DUARTE PINTO, Serge (CERN)

Co-authors: DAVID, Eric (CERN); SAULI, Fabio (TERA); CROCI, Gabriele (CERN); TAUREG, Hans (CERN); BROCK, Ian (Physikalisches Institut der Universitaet Bonn); BROCK, Ian (Bonn University); ROPELEWSKI, Leszek (CERN); ALFONSI, Matteo (CERN); VAN STENIS, Miranda (CERN); DE OLIVEIRA, Rui (CERN)

Presenter: VILLA, Marco (CERN)

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