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A study of film and foil materials for the GEM detector proposed for the CMS muon system upgrade

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ABSTRACT: During the next shutdown of the LHC at CERN, the CMS experiment plans to start installing GEM detectors in the endcap (high pseudorapidity) region. These muon detectors have excellent spatial and temporal resolution as well as a high chemical stability and radiation hardness. A report is given on preliminary results of materials studies that aimed to fully characterize the GEM detector components before and after the exposure to a high-radiation environment.

KEYWORDS: Muon spectrometers; Materials for gaseous detectors; Manufacturing; Detection of defects

Contents

1 Introduction

The Compact Muon Solenoid (CMS) [1] is a precise and hermetic particle detector with an excellent muon detection system. Muons traversing the system are reconstructed and identified by a robust, redundant and efficient system, which also provides trigger capabilities. For the initial phase of CMS, three types of gaseous detection technologies have been chosen: Drift Tubes (DTs) and Cathode Strip Chambers (CSCs) in the barrel and endcaps, respectively, and Resistive Plate Chambers (RPCs) in both the barrel and the endcaps.

The proposal for the upgrade of the CMS muon forward system comprises Gas Electron Multiplier (GEM) chambers [2, 3] to be installed during the second Long Shutdown (LS2) of the Large Hadron Collider (LHC) and covering the pseudorapidity range $1.5 < |\eta| < 2.2$. Challenges for this detector being addressed consist of possible aging, due to both the presence of highly radiogenic environments and to the interaction with gas mixture and system fluids. Furthermore, standard procedures for proper quality control during the detectors production and operation need to be determined.

After identifying the parameters of interest for the characterization of the materials which compose the GEM detector, we report on preliminary results on studies of diffusion of water in the detector materials, and on tensile properties of mechanically tensioned (i.e., stretched) chamber elements.

2 GEM detector for CMS

The GEM detector shown in figure 1 is a thin Cu-coated polyimide foil perforated with a high density of holes, where each hole is acting as multiplication region. Single GEM foils can operate up to gains of several thousands and can be used in cascade. The cathode-anode voltage is distributed to each foil via a high voltage divider. Each foil gap potential is typically 400 V. Triple-GEM detectors [4], made with three GEM foils in cascade, ensure high gains and safe operation at low
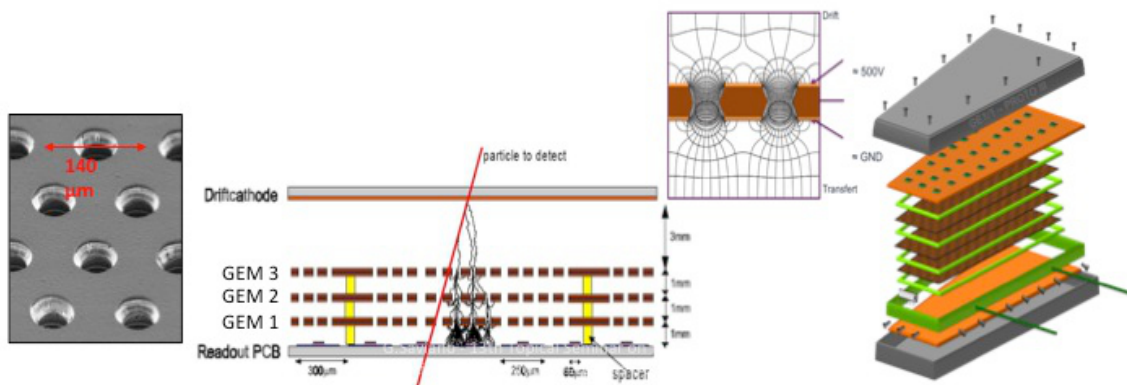
Figure 1. The GEM Detector; from right to left: triple GEM, electric field around the holes in a GEM foil, electron multiplier layout in triple GEM detectors, holes in a GEM foil.

voltage. The GEM detector for CMS bases its operation on ionization of a gas mixture consisting of $Ar/CF_4/CO_2$ (45:40:15). Each polyimide (kapton $50\,\mu m$ thick) layer has both surfaces coated by $5\,\mu m$ thick Cu deposited by a sputtering process and patterned with a plot of biconical holes ($D = 70\,\mu m$, $d = 50\,\mu m$), with a triangular mesh ($p = 140\,\mu m$) trapezoidal profile. Typical trapezoidal foil dimensions are $990\,mm \times (220\text{–}455)\,mm$. The structure is denoted as GEM foil, and it must be mechanically tensioned (i.e., stretched) during the assembly to reach the right state of parallelism (within $100\,\mu m$ over a 1 mm spacing). For a recent review of the GEM detector proposed for CMS see [5].

3 GEM materials

A systematic study of the materials composing the detector is in progress in order to monitor possible changes of properties and behaviours of the chambers as a result of interaction with fluids (gas mixture, air, etc.) and radiations. This study is focused on the contact of GEM foils with environmental air and moisture, i.e., both on amount and timing of the diffusion of water in the detector polyimide. The presence of this compound inside the detector sheets can determine a change of mechanical and electrical properties.

The materials studied in this paper were kapton and GEM foils. Studies are ongoing on gas mixture, glue, cured resins, O-rings, gas inlet/outlet, screws, washers etc.

3.1 Reference state

Analyses have been performed on unused samples of kapton and GEM foils in order to gather data for later comparison with samples to be irradiated at the GIF (Gamma Irradiation Facility) at CERN. In order to obtain the acquisition of the reference values (i.e., the material properties of unused samples), FTIR (Fourier Transform Infra Red) analysis, optical microscopy and SEM-EDS (Scanning Electron Microscopy — Energy Dispersive Spectrometry) characterization (figure 2) were performed [6].
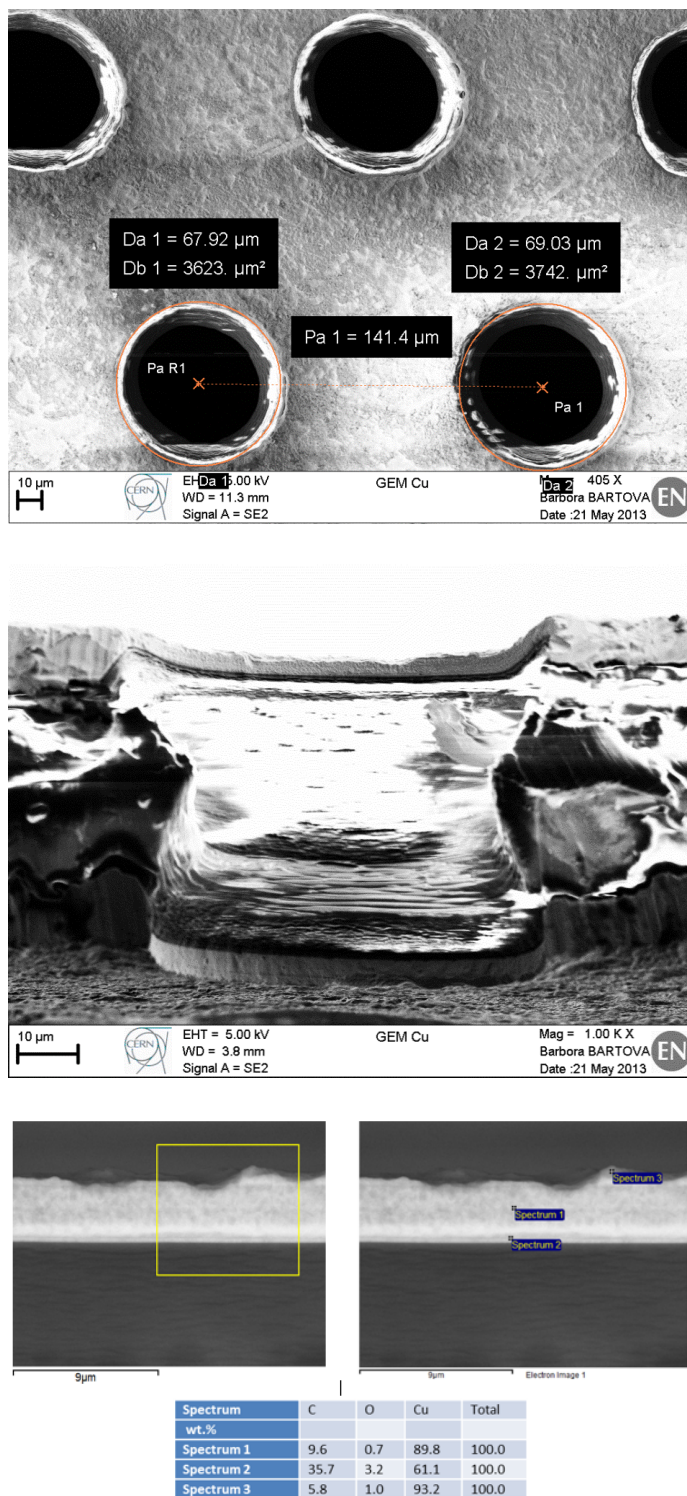
Figure 2. Microscopy images (top, centre) and EDS analyses results table from SEM-EDS on a GEM foil section (bottom). Table shows relative amounts of C, O and Cu measured in the three cross-sectional spots analyzed.

Figure 3. Experimental setup for the measurement of the diffusion coefficient of kapton/water and GEM/water systems.

3.2 Interaction of GEM foils with humidity

GEM foils interact with humidity both before assembly because of cleaning procedures where water is used, and via atmospheric air intake by means of leaks in gas piping. It is very important to characterize the GEM foil behaviour as a function of humidity in order to determine the amount of water contained in the chambers during the detector operation. Water content is expected to affect both electrical and mechanical GEM foil properties.

Diffusion of water in the GEM foil as a function of time was parameterized [7] according to formula

$$\frac{M(t)}{M(\infty)} = 1 - \frac{8}{\pi^2} e^{-\frac{D\pi^2 t}{4\ell^2}} \tag{3.1}$$

where $M(t)$ is the mass of water adsorbed on kapton foil surface and diffusing at time t, $M(\infty)$ is the mass of water at equilibrium (saturation), D is the diffusion coefficient of water in kapton and ℓ is the half-thickness of polyimide layer.

Two GEM samples with dimensions $10\,\text{mm} \times 15\,\text{mm} \times 60\,\mu\text{m}$ and approximate weight of 1 g (at dry condition) were pre-conditioned in oven at $100\,°\text{C}$ for 36 hours. The oven conditioning is required in order to have completely dry samples suitable to the measurement of the total water adsorbed. Samples were located in a dryer vessel (figure 3) with controlled humidity obtained using a K-carbonate saturated solution (45% relative humidity, RH) along with a standard hygrometer to monitor internal conditions. The samples weight was measured while increasing due to water absorption. Data were collected in continuum, i.e., without removing the samples from vessel, by
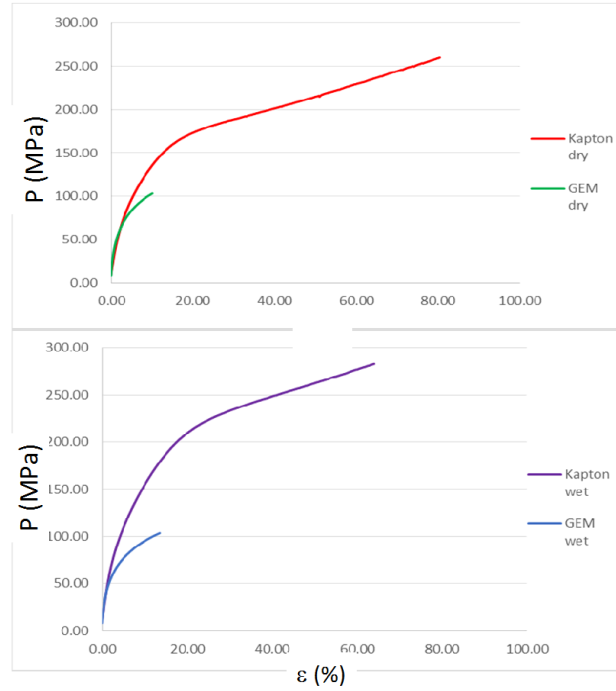
Figure 4. Kapton and GEM mechanical properties during tensile stress test. Load applied is shown as a function of relative elongation.

using a remotely controlled analytical balance. The test was operated at controlled environmental parameters typical of GEM operation, i.e. $T = (20\text{--}22)\,°\text{C}$ and $RH = (45\text{--}50)\,\%$.

The constant of diffusion of water in the GEM foils D_{GEM} was determined by best fit of eq. (3.1) to data. Preliminary results yield

$$D_{\text{GEM}} = [3.3 \pm 0.1(\text{stat})]10^{-10}\text{cm}^2/\text{s} \tag{3.2}$$

where the error is statistical only. The value found corresponds to a saturation time (i.e., time needed to reach equilibrium) of 8.5 hours.

Further tests are in progress in the next months to optimize the drying procedure, and to estimate the measurement systematics.

3.3 Humidity influence on kapton and GEM mechanical properties

The mechanical response of materials was analyzed by means of uniaxial tensile tests [8–11] for samples of kapton and GEM foils, in both dry and wet conditions. Four samples of GEM foils $[10\,\text{mm} \times 110\,\text{mm} \times 60\ (50\,\mu\text{m kapton} + 5\,\mu\text{m Cu} + 5\,\mu\text{m Cu})\,\mu\text{m}]$ and four samples of kapton $(10\,\text{mm} \times 100\,\text{mm} \times 50\,\mu\text{m})$ have been dried at 100 °C for 36 hours and tested using standard industrial procedures [8]. For the test in humidity, the samples were humidified at $RH = 99.5\,\%$ for 7 days prior to measurement.

Figure 4 shows preliminary results of the tensile tests. The load applied (P) is shown as a function of the fractional elongation σεрu As expected, the GEM foil shows a slight increase of Young's modulus compared to the kapton foil, due to the presence of Cu coating. Furthermore, the

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holes for electronic multiplication are harmful to the resistance of the structure, thus behaving as defects and amplifying local stress. Humidity has a larger effect on kapton than on GEM foils due to Cu coating.

4 Conclusions

Preliminary results on an ongoing detailed campaign of measurements aimed to characterize the GEM foils with respect to their chemical, electric and mechanical properties, and to understand how they are affected by environmental conditions were shown, including the first measurement of water diffusion coefficient, measurements of tensile properties for both dry and wet GEMs, in comparison to kapton foils. Exposure of samples to high radiation doses is ongoing and measurements will be repeated to ascertain the effect of radiation on these materials.

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