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CMS GEM detector material study for the HL-LHC

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Abstract

A study on the Gaseous Electron Multiplier (GEM) foil material is performed to determine the moisture diffusion rate and saturation level and the moisture effects on its mechanical properties. The study is focused on the foil contact with ambient air and moisture to determine the value of the diffusion coefficient of water in the detector polyimide. The presence of water inside the detector foil can determine the changes in its mechanical and electrical properties. A simulated model is developed by taking into account the real GEM foil (hole dimensions, shapes and material), which describes the adsorption on a sample. This work describes the model, its experimental verification, the water diffusion within the entire sheet geometry of the GEM foil, thus gaining concentration profiles and the time required to saturate the system and the effects on the mechanical properties.

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CMS GEM detector material study for the HL-LHC

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A study on the Gaseous Electron Multiplier (GEM) foil material is performed to determine the moisture diffusion rate, moisture saturation level and the effects on its mechanical properties. The study is focused on the foil contact with ambient air and moisture to determine the value of the diffusion coefficient of water in the foil material. The presence of water inside the detector foil can determine the changes in its mechanical and electrical properties. A simulated model is developed with COMSOL Multiphysics v. 4.3 [1] by taking into account the real GEM foil (hole dimensions, shapes and material), which describes the adsorption of water. This work describes the model, its experimental verification, the water diffusion within the entire sheet geometry of the GEM foil, thus gaining concentration profiles and the time required to saturate the system and the effects on the mechanical properties.

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1. Introduction

The Gaseous Electron Multiplier (GEM) detector has been approved for the upgrade of the forward muon system of Compact Muons Solenoid (CMS) at Large Hadron Collider (LHC). The GEM detector provides good timing and position resolution and it meets the particle detection requirements in the eta region $1.6 < \eta < 2.2$, where high particle flux 5 kHz/cm^2 is expected [2] [3]. The principal component of the detector is a GEM foil (Cu-cladded (5μm), micro perforated 60 μm-thick kapton film), that provides charge amplification thanks to the conical shape of very dense micro holes.

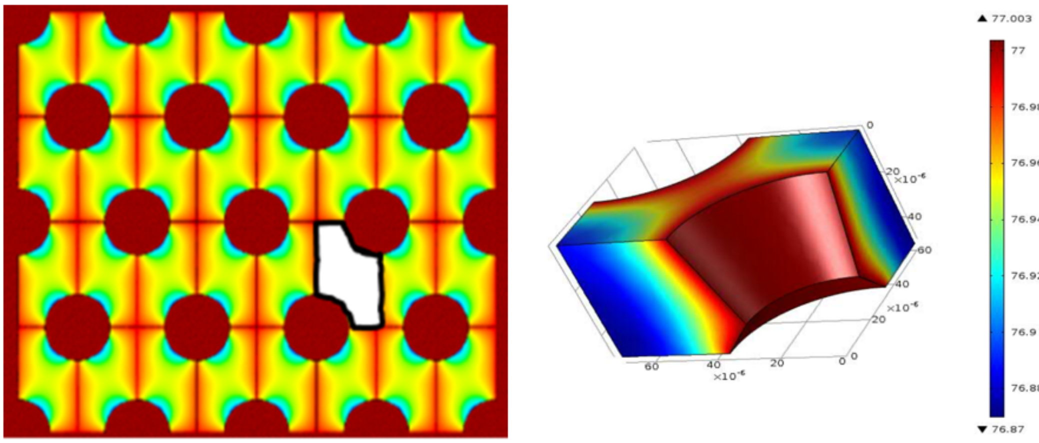

Figure 1: (left) Geometry of a GEM and detail analysis part is in black and white [5], (right). Concentration profile after 44400s with RH = 4 %.

2. Development of a diffusion model using COMSOL Multiphysics

This study considers the diffusion of H_2O from the hole surface only, since no penetration in polyimide is possible through Cu which behaves as a waterproof barrier. The presence of any stagnant H_2O film around the surface of the hole is also neglected, since the gas is continuously flushed inside the chamber, thus allowing to always have a constant and uniform concentration on the surface of the hole, i.e., results represents the maximum concentration of water that can get inside the structure considered. In general, moisture comes from the surrounding environment and spreads within the polyimide. The relationship used to obtain the value of this concentration on the surface of a polyimide as a function of the external humidity is derived from the literature [6]

$$c_1 = 4.520 \times 10^{-4} \times RH - 8.319 \times 10^{-4} \tag{2.1}$$

where c_1 expressed in grams of water to grams of polyimide. The formula used is empirical and it is compatible with the official data released by the manufacturer [7].

3. Experimental setup for verification of the diffusion model

The test apparatus setup in the Frascati INFN Lab consists of a weighing balance "Analytic balance Gibertini E42S", whose measurements are recorded by using a camera in front of the analytical balance display and connected to a computer. A data acquisition program is used to record weight measurements with constant time intervals. The sample used for this test has dimensions of 105 mm $\times$ 50 mm $\times$ (50 + 5 +5) μm, and it was previously conditioned in an oven at (105 $\pm$ 5) ^{o}C for 36 hours.

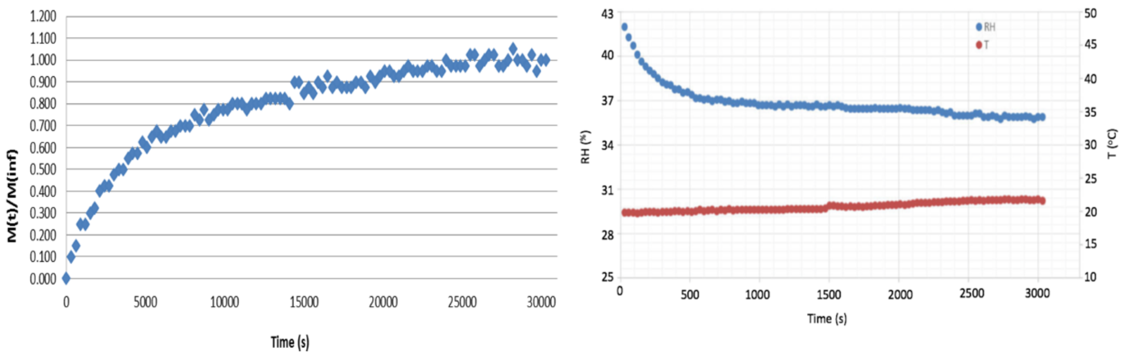

Figure 2: (left). Saturation trends of the GEM foil, (right). Temperature (T) and Relative Humidity (RH) in the container during the test.

4. Moisture and dryness effects on the GEM and kapton tensile properties

To dry GEM and kapton samples an oven at 99 ^{o}C is used for 36 hours. Conditioning to a wet state is accomplished by keeping samples at 99.5 % relative humidity and room temperature (25 ^{o}C) for five days. Tensile tests were performed in displacement control using a crosshead speed of 10 mm/min and a gauge length of 70 mm by means of a Zwick/Roell Z010 according to ASTM D882-02 standard. The measurements were performed at room temperature (25 ^{o}C) until final failure of the samples occurred. Each set such as GEM dry, GEM wet, kapton dry and kapton wet has four samples.

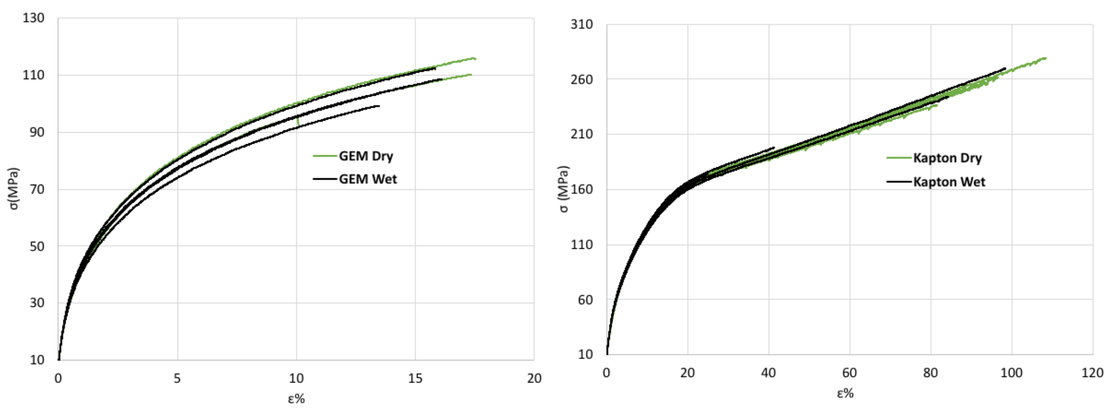

Figure 3: (left) Tensile stress vs elongation trends for kapton dry and wet, (right). Tensile stress vs elongation trends for GEM dry and wet.

Table 1: Young's modulus of kapton and GEM foil

Condition	Kapton Young's modulus (MPa)	GEM Young's modulus (MPa)
Dry	2385 ± 20	6026 ± 119
Wet	2529 ± 57	6314 ± 254

5. Results discussion

The simulation results showed that the saturation time is about 10 hours at RH = 4 %, 14 hours at RH = 40 % and 100 %, starting from a null value of water inside. The concentrations limits are different 75 mol/m^3, 1380 mol/m^3 and 3450 mol/m^3 at different relative humidity values 4 %, 40 % and 100 % respectively [8]. In figure 1, the geometry of a GEM and concentration profile after 44400 s with RH = 4 % is shown.

After the conditioning in oven, the sample is weighed and a value of (0.6575 ± 0.0002) g is found, while the bolt placed on the scale plate had a weight of 5,725 mg. The humidity and temperature range during this test is selected as RH = 34-36 % and T = 19 - 20 ^{o}C, the images are taken from every 5 minutes interval. The trends of saturation along with temperature and humidity during tests are shown in figure 2, showing how in 8-9 hours it is possible to saturate completely the GEM foil. These results confirm the model in [8]. Furthermore, the measurements showed the presence of 0.004 g water at saturation, comparable with what is obtained from the official data sheet by the manufacturer [7] or from equation 2.1, for a value of RH = 37.5 %. By using the experimental data, we calculated the diffusion coefficient of water in the foil as $D_{GEM} = (3.3 \pm 0.1$ (stat))10^{-10} cm^2/ s [9].

Tensile trends of GEM and kapton are shown in figure 3. An average Ultimate Tensile Stress (UTS) and elongation values of the dry GEM are 106.0 ± 12.2 MPa and 14.9 ± 4.2 % respectively. Similarly, for the wet GEM the average UTS and elongation values are 106.3 ± 5.3 MPa and 14.9 $\pm$ 1.2 % respectively. An average UTS and elongation of the four dry kapton samples is 258.2 $\pm$ 17.6 MPa and 95 ± 11 %, respectively and for the wet kapton the figures are 221.1 ± 43.2 MPa and 62 ± 34 %, respectively. Measurements of UTS and elongation showed that within the experimental errors; the dry kapton is stronger than the wet kapton. For GEM foils it is shown how average UTS values see no difference between dry and wet. Young's modulus is estimated from stress vs strain data and is shown in table 1.

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