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Enhanced discharge robustness of large-scale resistive WEM detectors with diamond-like carbon anode

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Abstract. A prototype of the large-scale resistive WEM (Well Electron Multiplier) detector with enhanced discharge robustness was developed, produced and tested. The WEM detector is composed of a perforated board (500 μm thick with drilled holes of 200 μm in diameter and 500 μm in pitch) and resistive anode-readout board with high voltage copper grid on one side (500 μm in pitch and 100 μm in strip width) and readout pads on the other side. The resistive anode was made by coating the high voltage grid electrode with diamond-like carbon (DLC) resistive layer of 100 nm thick with sheet resistance of 30 MOhm/square. To improve the robustness of the large-scale WEM, we insulated the grid electrode with a 50 μm thick microstructured insulator using a photolithography technique with parameters that provide the best detector performance according to simulation in Comsol Multiphysics software. Preliminary tests revealed stable operation of the developed detector confirming the results of math simulations. The proposed approach allows developing the robust large-area WEM detectors for high-energy physics experiments, which simultaneously have great potential for material sciences, medical imaging, hadron therapy and muon tomography.

Keywords: Micropattern gaseous detectors, diamond like carbon, robustness, electrical discharges.

1. Introduction

Well Electron Multiplier (WEM) detector with an anode composed of a high voltage grid and diamond - like carbon (DLC) coating was earlier proposed as Micro Pattern Gas Detector (MPGD) with a high robustness in operation with electrical discharges [1]. The WEM detector is composed of two parts. The first is a 500 μm thick FR4 board metallized on one side with drilled holes of 200 μm in diameter and 500 μm in pitch. The second FR4 board contains copper grid metallization on one side and readout electrodes at the bottom. The grid electrode and FR4 inside the cells were coated with DLC resistive layer. Two boards were combined together into a single multilayer board in such a way that the grid conductors are located between the holes of the perforated board and DLC coated the second FR4 board is below the holes. The anode grid is used to improve electron evacuation, while the resistive DLC layer with a sheet resistance of 30 MOhm/square is supposed to reduce the electrical current discharges produced by highly ionizing particles.

It was earlier shown in experiments with ^{241}Am alpha source that WEM detector with an active area of 10 x 10 mm demonstrates a high robustness in operation with electrical discharges [2]. At the same time the simulation of the behavior of a large area WEM detector revealed a significant damage of high voltage grid electrode and DLC layer for area more than 60 x 60 mm^2. The reason of the detected damage was assumed to be a 35 µm gap between the perforated FR4 board and the anode resistive board caused by the presence of the high voltage grid electrode.

In this paper we demonstrate that insulating of the grid electrode with a 50 µm thick microstructured solder mask significantly enhance a discharge robustness of large-scale resistive WEM detectors.

2. Results and discussion

The parameters of the insulating structure were determined based on the best detector performance according to simulations of electric field distribution done with Comsol Multiphysics software. The most optimal structure appears to be a perforated layer with holes of 300 µm in diameter and 500 µm in pitch that insulates the anode grid electrode. It was produced for WEM detector with an active area of 60 x 60 mm by photolithography technique using photosensitive liquid soldering mask. Anode FR4 board with a high voltage grid was developed and produced with parameters similar to that described previously in [1, 2], but with area 60 x 60 mm^2.

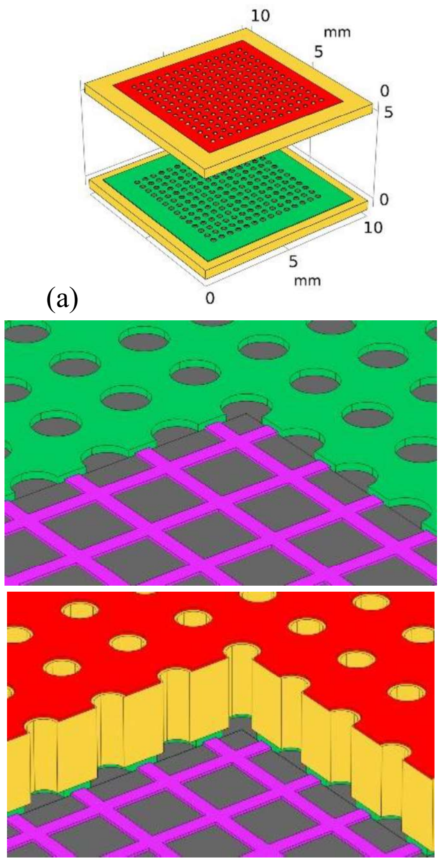

Figure 1. Sketch of WEM detector consisting of two boards (a) and enlarged sketch of insulating microstructure of a resistive DLC anode with a high voltage grid alone (b), combined with perforated FR4 board (c).

DLC layer was deposited using the cathodic Arc physical vapor deposition (Arc-PVD) in a chamber with the pressure of 10^{-5} mbar [3]. The surface of the anode plate was preliminarily cleaned by low-energy Ar^+ ions during 10 minutes. The layer of DLC with the thickness of 100 nm was deposited by two pulsed carbon plasma generators spaced in height and operating alternately at the voltage of 300 V with the frequency of 0.25 Hz [4]. Sheet resistance was controlled using two opposite arrears 10x10 mm near the anode high voltage electrode (Fig. 2). The obtained value of sheet resistance for the anode surface is 30±2 MOhm/square.

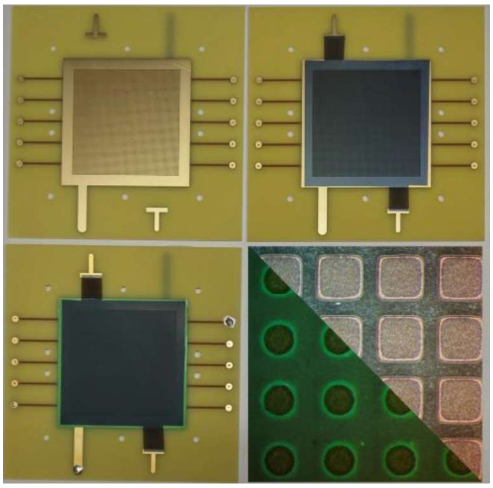

Figure 2. A photographic image of anode FR4 board with high voltage grid coated with DLC and insolating structure.

The discharge events in the WEM detector were initiated by an ^{241}Am alpha source with the activity of 33 Bq placed in the detection volume on the surface of the drift cathode over the center of the active area of the detector. The number of the discharge events was counted with a discriminator circuit connected to a counter module. The detector was flushed with the gas mixture $Ar:CO_2$ (70:30) at atmospheric pressure and room temperature with rate about 1 l/h. A negative high voltage was applied to the cathode to provide drift electric field in the detection gas volume of the detector. The electrode of perforated board was connected to the ground. A positive high voltage was applied to the anode grid electrode and was distributed to the resistive DLC layer. The induced signals were registered from readout strips with a charge sensitive amplifier and digitized with an ADC. The detector accumulated 100,000 discharges at a gain of 3500, similar to the experiment described earlier in [2]. After the experiment, the WEM detector was disassembled and the anode board was carefully examined. No visible traces of electrical discharges were found on the surface of the isolating microstructure or DLC layer.

The structure properties of DLC layer were examined using Nanofinder HE confocal Raman spectrometer at room temperature in the back scattering configuration with a solid state laser of the wavelength of 473 nm. Optical power incident on DLC layer was reduced down to 80 μW for 30 s exposition per spectrum to avoid background luminescence and possible heating damage. Raman spectra before accumulating 100,000 discharges an after (see Fig. 2) demonstrate the strong luminescence background from FR4 substrate in the whole wave number range.

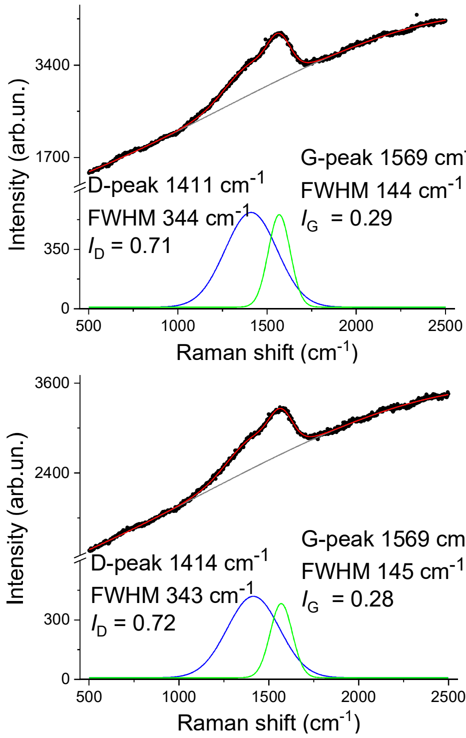

Figure 3. Raman spectra of DLC coating before (a) and after (b) accumulating 100,000 discharges.

The fitting of Raman peaks was performed using a Gaussian distribution. The main bands, known as D and G peaks, are located at around 1410 cm^{-1} and 1570 cm^{-1} respectively. The G peak corresponds to zone center E_{2g} mode, while D peak – to zone-edge A_{1g} mode [5]. The line shapes of D and G peaks reflect the quality of the DLC films. The intensity ratio I_D / I_G = 2.5 ±0.1, obtained by spectrum approximation, corresponds to the concentration ratio of sp^2- to sp^3-hybridized carbon bonds denoting the a-C form of DLC with almost 30% of carbon atoms with tetrahedral coordination [6].

According to the results of spectroscopy, the structure of DLC layer did not undergo any significant changes after accumulating 100,000 discharges.

To simulate the behavior of a detector with area more than 100 x 100 mm^2, we added a capacitance of 1 nF in parallel with the anode high voltage grid and top electrode of perforated FR4 board. After accumulating 100,000 discharges the performance of WEM detector did not change and there was no visible damage to the DLC layer. It denotes that the insulating of high voltage grid provides an enhanced discharge robustness of large-scale resistive WEM detectors with diamond like carbon anode with grid electrode.

3. Conclusion

The use of grid anode electrode in WEM detector significantly improve electron evacuation increasing it rate capability from one hand. From the other hand, the high voltage grid has a final thickness that results in a gap between the perforated FR4 board and the resistive anode board. The electric field strength in this gap has a local maximum. This increases the likelihood that the discharge channel will not pass through the resistive layer directly below the multiplication hole, but instead will pass through the gas in the gap and terminate in the high voltage grid. It limits the segment size of proposed earlier WEM construction.

To improve the robustness of WEM with area 60 x 60 mm^2, we insulated the grid electrode with a 50 µm thick microstructured insulator using a photolithography technique with parameters that provide the best detector performance according to simulation in Comsol Multiphysics software. Preliminary tests revealed perfect operation of the developed detector.

The simulation of detector performance with area 100 x 100 mm revealed its robustness in operation with electrical discharges.

The proposed approach allows developing the robust large-area resistive WEM detectors with high rate capability for high-energy physics experiments, which simultaneously have great potential for material sciences, medical imaging, hadron therapy and muon tomography.

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