Numerical Evaluation of Electric Field and Dark Current of Resistive Plate Chamber

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Abstract. We have developed a numerical model to simulate the electric field and dark current of RPC from the first principle using finite element method. The effect of the electrical properties of electrode and spacer materials on field configuration and dark current has been systematically investigated for optimization of RPC design using the model.

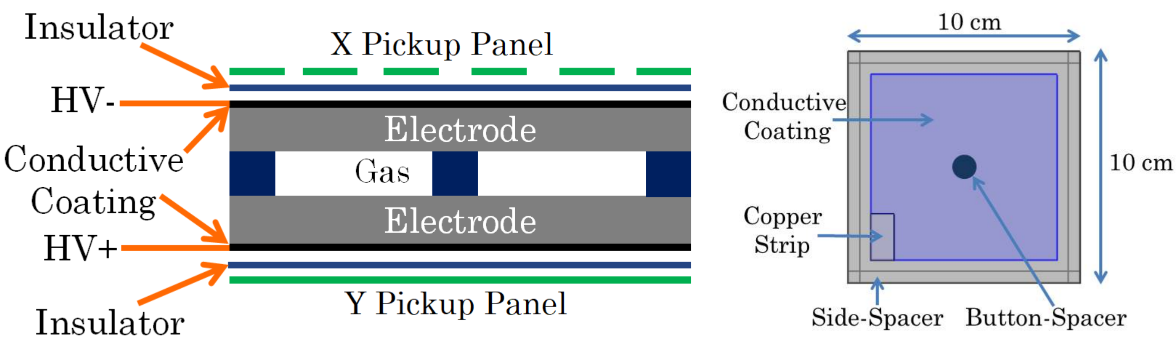
1. Introduction

Resistive Plate Chamber (RPC) is a gaseous detector with parallel plate configuration, known for its excellent time and spatial resolution. Its working principle relies upon the amplification of primary electrons created in its gas volume due to passage of charged particles under the influence of an externally applied electric field. It is generated by supplying high voltages to the conductive coating applied on the resistive plates. The performance of the RPC is largely governed by the field configuration where the electrical properties of the device components play an important role. In this work, we have numerically simulated the electric field distribution and dark current of RPC due to the applied voltage across its resistive electrodes to investigate the effect of bulk resistivity of the electrode and spacer materials and surface resistivity of the conductive coating. This study has helped us to identify the appropriate choice of these parameters to get an optimal performance of RPC.

2. Construction and Operation of RPC

As illustrated in figure 1(a) an RPC is constructed with two parallel plates of high bulk resistivity, such as glass or bakelite [1, 2]. The gap between the plates is sealed with spacers from all sides for holding the active gas volume. A suitable gas mixture is circulated through the nozzles fixed on the side-spacers. To maintain the uniformity of the gap between the plates, button-shaped spacers are used. The outer surface of the resistive plates is coated with a thin layer of conductive paint where the high voltage supply is connected. Two pickup panels made of copper strips pasted on insulating boards are fixed outside the electrodes for collection of signal. They are insulated from the conductive coating by a thin insulating layer.

The primary electron-ion pairs created from the ionization of the gaseous molecules due to their interaction with the passing particle, drift towards respective electrodes under the action of the applied electric field. The primary electrons undergo multiplication through further interaction while moving towards the anode. The ions on the other hand drift slowly and therefore create minimal ionization. The electronic avalanche causes a drop in the voltage applied at the electrodes. The high bulk resistivity of the electrodes ensures that such a drop is localized near the avalanche site. It governs also the time of dissipation of the charges. Thus, a higher bulk resistivity of the electrodes reduces the breakdown in one hand and increases dead time on the other leading to a reduction in rate capability. Smaller surface resistivity of the conductive coating implies that a larger area will observe the voltage drop and more number of copper strips of the pickup panel will fire.



(a) Schematic RPC configuration (b) XY-plane view

Figure 1: Resistive Plate Chamber (RPC)

3. Simulation Model

The simulation of electric field configuration and dark current for the given design of RPC has been carried out using COMSOL Multiphysics [3]. The geometrical model of RPC used in the simulation has been described below followed by the mathematical model implemented in the calculation.

3.1. Model Geometry

A 3D-model of RPC of dimension 10 cm $\times$ 10 cm with 3 mm thick electrodes and a 2 mm gas-gap has been used. Side-spacers of width 5 mm and thickness 2 mm and a button-spacer of diameter 10 mm and thickness 2 mm have been considered. The area of the conductive coating on the electrodes has been made 8 cm x 8 cm leaving a gap of 10 mm from all the sides following the usual practice for avoiding the discharges across the edges of the electrodes. Following the construction, a small copper strip for provision of high voltage supply has been considered at one corner of the conductive coating. The insulating layer and the pickup panel beyond the electrode have not been considered as there should not be any influence of these components on the field configuration. The geometrical model of the RPC is shown in figure 1(b).

3.2. Mathematical Model

The electric field and dark current in the RPC have been calculated by using the "Electric Currents" module where the following equations have been solved.

$$\vec{\nabla} \cdot \vec{J} = Q_{j,v} \qquad \vec{J} = \sigma \vec{E} + \vec{J}_e \qquad E = -\vec{\nabla} V$$

Here, V and $\vec{E}$ are the potential and electric field respectively, $\vec{J}$, the current density, $\vec{J}_e$, the external current density, σ, the electrical conductivity and $Q_{j,v}$, the rate of change in volume

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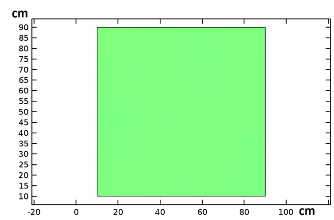
charge density. The high voltage applied on conductive coating and other material properties, like resistivity and permittivity of the detector materials have been provided as input to the model. The infinite bulk resistivity of the gas in absence of any ionization phenomenon has been considered by using a very high value of about 10^{20} $\Omega\,$cm and its relative permittivity same as that of the vacuum.

4. Simulation Results

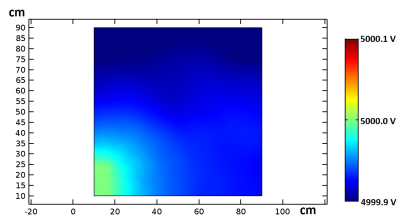
Here, all the results of the voltage distribution on the electrodes, dark current density in different components and field configuration within the active volume obtained for various electrical properties of the materials will be discussed.

4.1. Surface Resistivity

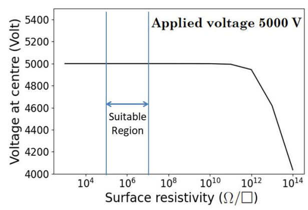
In figure 2(a) and 2(b), the voltage distribution on the conductive coating has been shown for two values of surface resistivity, 500K Ω/□ and 100M Ω/□ respectively. It can be seen from the plots that the low resistivity has allowed a uniform voltage distribution on the electrode surface. However, it can create a shielding effect on induction of the output signal on the pickup panel lying outside [4]. The figure 2(c), which shows the voltage at the middle of the coated surface with varying surface resistivity, implies that the surface resistivity within a range of 500K to 1M Ω/□ is suitable for uniform voltage distribution as well as induction of the output signal.



(a) Surface resistivity = 500K Ω/□



(b) Surface resistivity = 100M Ω/□



(c) Voltage at the centre with varying surface resistivity

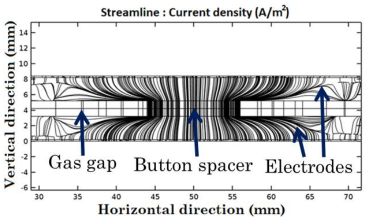
Figure 2: Voltage distribution for different values of surface resistivity of conductive coating

4.2. Dark Current Configuration

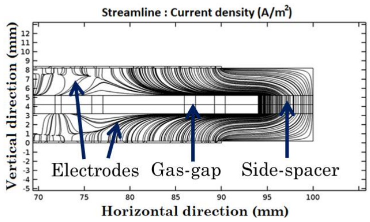
The simulation has shown that the maximum current flows through the side and button spacers as the bulk resistivity of the gas medium is extremely high in comparison to that of the other components. The current density streamlines at different locations of the RPC have been depicted in figure 3(a) and 3(b). The amount of dark current is governed by the resistivity of the spacer material as its value is higher in comparison to that of the electrodes [5]. From figure 3(c), it can be found that the current variation with the change of electrodes' resistivity for a given resistivity of the spacer material is nearly negligible while that is substantial with the change in spacer resistivity for a given electrode resistivity. It implies that the choice of spacer material is a crucial part of RPC construction.

4.3. Electric Field Distribution

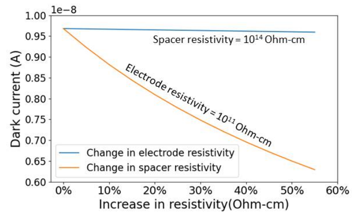
It has been found from our study that the bulk resistivity of the electrodes and spacers collectively play an important role in governing the RPC performance. Electric field distribution inside gas-gap with different electrical properties of electrode and spacer combinations are shown in figure 4. It can be noted from the plots that the electrode material with bulk resistivity from 10^{10} to 10^{12} $\Omega\,$cm and the spacer material with bulk resistivity from 10^{14} to 10^{15} $\Omega\,$cm are the suitable choices for the present RPC configuration.



(a) Current density through button spacer

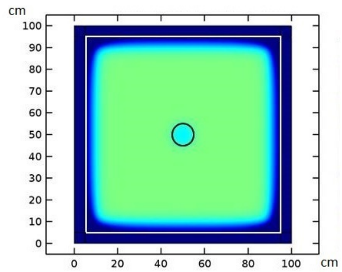


(b) Current density through side spacer

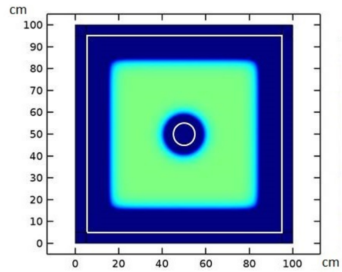


(c) Current with varying electrode and spacer resistivity

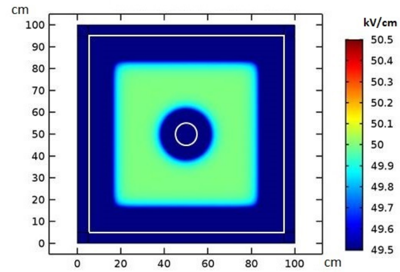
Figure 3: Current density and current with varying spacer conductivity and electrode conductivity



(a) Spacer resistivity = $10^{14}\Omega\,$cm, electrode resistivity = $10^{11}\Omega\,$cm



(b) Spacer resistivity = $10^{14}\Omega\,$cm, electrode resistivity = $10^{13}\Omega\,$cm



(c) Spacer resistivity = $10^{13}\Omega\,$cm, electrode resistivity = $10^{13}\Omega\,$cm

Figure 4: Electric field inside gas-gap with different electrodes and spacer combinations.

5. Conclusions

The simulation of the voltage distribution, dark current and field configuration has provided us with a few criteria about the choice of materials in the construction of RPC. The surface resistivity of the conductive coating between a range of 500K to 1M $\Omega/\square$ is suitable to maintain uniform distribution of high voltage on the electrodes. The total amount of dark current is governed by the bulk resistivity of the spacer material. Higher spacer resistivity relative to that of the electrode gives better electric field uniformity. In future, we have plans to study the effect of pickup panels and non-uniform coating surface resistivity on electric field distribution and dark current. A few experimental measurements will also be carried out to corroborate the simulation results.

Acknowledgments

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