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Design and Optimization of Resistive Anode for a Two-Dimensional Imaging Triple-GEM Detector (Postprint)

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Abstract

The optimization of resistive anodes for two-dimensional imaging detectors, which consist of a series of high-resistivity square pads surrounded by low-resistivity strips, has been studied through both numerical simulations and experimental tests. It has been found that to achieve good detector performance, the resistance ratio of pads to strips should be greater than 5, the nonuniformity of pad surface resistivity should preferably be less than 20%, a smaller pad width leads to a smaller spatial resolution, and when the pad width is 6 mm, the spatial resolution ( ) can reach approximately 105 m. Based on these results, a 2-D GEM detector prototype with the optimized resistive anode has been constructed, achieving good imaging performance.

Full Text

Preamble

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Design and optimization of resistive anode for a two-dimensional imaging triple-GEM detector

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Abstract

The optimization of resistive anode for two-dimensional imaging detectors, which consists of a series of high-resistivity square pads surrounded by low-resistivity strips, has been studied through both numerical simulations and experimental tests. The results indicate that to obtain good detector performance, the resistance ratio of the pad to the strip should be larger than 5, the nonuniformity of the pad surface resistivity should preferably be less than 20%, and a smaller pad width leads to improved spatial resolution. When the pad width is 6 mm, the spatial resolution ( ) can reach approximately 105 μm. Based on these findings, a 2-D GEM detector prototype with an optimized resistive anode was constructed, demonstrating excellent imaging performance.

Key words: resistive anode, GEM, two-dimensional detector, spatial resolution, imaging distortion
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Introduction

The Gas Electron Multiplier (GEM) detector, an important member of the Micro-Pattern Gaseous Detectors (MPGD) family, has been widely employed in particle physics experiments such as CERN-COMPASS due to its superior properties, including excellent spatial resolution, high counting rate capability, and low material budget. Compared to traditional gaseous detectors like drift chambers, the GEM detector offers the distinct advantage of separating the readout electrode from the multiplication region, enabling various readout methods such as 1-D strip, 2-D strip, and pixel configurations. However, conventional readout approaches typically require a large number of electronic channels—for instance, the GEM detector in KLOE2 incorporates approximately 30,000 channels. Consequently, numerous novel readout structures have been developed to reduce electronic channel count.

The resistive readout method, widely used in Position Sensitive Detectors (PSD), represents one such innovation. Sarvestani et al. developed a 2-D interpolating resistive readout structure for Micro-CAT applications. This approach can provide good spatial resolution while dramatically reducing electronics channels, particularly when compared to pixel readout schemes. Building upon this concept, we developed a triple-GEM detector with a 2-D resistive anode. Our investigations revealed that the resistive anode parameters strongly influence detector performance, with certain configurations causing serious imaging distortions. To systematically study these effects, a series of anodes with different parameters was fabricated and tested. This paper presents a comprehensive optimization study of the resistive anode through both simulations and experiments.

2.1 Detector Setup and Principles

The experimental setup is similar to that described in Ref. [9], with the primary modification being an upgrade of the data acquisition system from CAMAC-Bus to VME-Bus. Figure 1 [Figure 1: see original paper] shows the schematic diagram of the detector configuration. Three cascading standard GEM foils from CERN serve as the gas amplification device. Electrons generated in the drift region by incident particles are multiplied in the GEM foil holes and subsequently drift to the resistive anode. The charge clouds induced in the induction region diffuse across the resistive anode surface and are collected by readout nodes located at cell corners. For the prototype study, 16 readout nodes covering a 3 × 3 cell array were equipped with charge-sensitive amplifiers and 12-bit peak-sensing ADCs, which interface with a PC through the VME-Bus.

The resistive anode is manufactured using thick-film resistor processing on a ceramic substrate, with its structure illustrated in Figure 2 [Figure 2: see original paper]. The sensitive area is divided into square cells, each consisting of three components: a high surface resistivity pad in the cell center (typical value of 100–1000 kΩ/ and dimensions of 7.8 mm × 7.8 mm), low surface resistivity strips surrounding the square pad (typical value of 1–10 kΩ/ and dimensions of 8 mm × 0.2 mm), and readout nodes at the four corners of each cell.

The properties of the resistive anode critically determine detector performance. Based on the structure shown in Figure 2, several parameters may affect anode quality: the resistance ratio of pad to strip, the dimensions of pads and strips, and the uniformity of pad surface resistivity. A series of resistive anode boards with varying parameters was fabricated to investigate how these factors influence detector performance, particularly spatial resolution.

2.2 Simulation Model

To understand the mechanism of charge diffusion on the resistive anode and provide a basis for anode structure optimization, a numerical simulation model was developed [10, 11]. Using differential Ohm's law, $\vec{j}(x,y,t) = -\sigma(x,y)\nabla V(x,y,t)$, where $\vec{j}(x,y,t)$ represents the surface current density, $\sigma(x,y)$ represents the surface conductivity, and $V(x,y,t)$ represents the potential, together with current conservation $\nabla \cdot \vec{j}(x,y,t) + c\frac{\partial V(x,y,t)}{\partial t} = 0$, the diffusion equation can be derived as:

$$\frac{\partial V(x,y,t)}{\partial t} - \nabla \cdot (\sigma(x,y)\nabla V(x,y,t)) = I(x,y,t)$$

where $I(x,y,t)$ represents the detector signal induced by electron clouds in the induction region. A Garfield++ [12] simulation was developed to evaluate $I(x,y,t)$, which is treated as a space- and time-dependent driving source $I(x,y,t) = I_0 S(x,y)T(t)$, with results shown in Figure 3 [Figure 3: see original paper]. In Equation (4), the spatial component of the detector signal ($S(x,y)$)

is simplified as a Gaussian distribution with $\sigma = 0.25$ mm, while the temporal component ($T(t)$) is simplified as a uniform distribution.

Charge diffusion on the resistive anode is thus abstracted as solving a partial differential equation with the constraint that the voltage at all readout nodes equals zero. The explicit finite difference method (FDM) is employed to solve this equation [10, 11].

2.3 Reconstruction Method

For position-sensitive detectors, the typical reconstruction method is the charge center-of-gravity (COG) approach. Considering the structural characteristics of the 2-D resistive anode readout method, the standard reconstruction technique is the so-called 4-node method [7]. This method uses the four nodes of the fired pad to reconstruct the hit position according to:

$$x = \frac{\sum_{i=1}^{4} x_i(Q_i - Q_{0i})}{\sum_{i=1}^{4}(Q_i - Q_{0i})}, \quad y = \frac{\sum_{i=1}^{4} y_i(Q_i - Q_{0i})}{\sum_{i=1}^{4}(Q_i - Q_{0i})}$$

where x_i and y_i represent the positions of the readout nodes, Q_i represents the charge measured by the electronics system, and Q_{0i} represents the baseline of the corresponding readout channel.

To reduce distortion caused by charge loss from the fired pad to adjacent pads, several improved methods have been developed [11, 13]. These more sophisticated reconstruction techniques can achieve better results by incorporating information from nodes on neighboring pads.

3.1 Resistance Ratio of Pad to Strip

Experimental investigations revealed that the resistance ratio of pad to strip significantly affects detector imaging performance. This ratio is defined as $R_{\square P}/(R_{\square L} \cdot N)$, where $R_{\square P}$ and $R_{\square L}$ are the surface resistivities of the pad and strip, respectively, and N is the aspect ratio of the strip.

Figure 4 [Figure 4: see original paper] presents simulation results for different values of $R_{\square P}/(R_{\square L} \cdot N)$. The pad and strip dimensions are 8 mm × 8 mm and 8 mm × 0.2 mm, respectively. $R_{\square L}$ is fixed at 1 kΩ/ , while $R_{\square P}$ varies from 1 kΩ/ to 400 kΩ/ across panels (a) through (h). The results show pincushion distortion in the imaging, which becomes more severe near pad edges. The primary cause is that a portion of the charge diffuses across strip boundaries and is collected by neighboring pads. Approximately 40% charge loss (defined as the percentage of charge collected by non-fired pads) occurs at pad edges when $R_{\square P} = R_{\square L}$ (Figure 4(a)).

Conversely, Figure 4 demonstrates that overall distortion decreases as $R_{\square P}/(R_{\square L} \cdot N)$ increases. In other words, a larger resistance difference between

pad and strip improves detector imaging performance, though this improvement saturates when $R_{\square P}/(R_{\square L} \cdot N) > 5$.

Based on these simulations, several resistive anodes with different $R_{\square P}/(R_{\square L} \cdot N)$ values were fabricated and tested in a GEM detector. The imaging performance is shown in Figure 5 [Figure 5: see original paper]. Compared to the anode with $R_{\square P}/(R_{\square L} \cdot N) \approx 3$, the anode with $R_{\square P}/(R_{\square L} \cdot N) \approx 5$ exhibits reduced pincushion distortion, consistent with simulation predictions.

In addition to imaging performance, distortion also affects spatial resolution. Figure 6 [Figure 6: see original paper] shows spatial resolution scans (σ, see Section 3.2) across a single pad in 1 mm steps for the resistive boards from Figure 5. Spatial resolution improves from the pad edge toward the center due to reduced distortion. For larger $R_{\square P}/(R_{\square L} \cdot N)$ values, σ is smaller and more uniform across the pad.

Furthermore, considering charge diffusion time on the resistive anode—particularly for anodes with high surface resistivity [10]—the recommended surface resistivity range for pads is 100–1000 kΩ/ , with $R_{\square P}/(R_{\square L} \cdot N)$ values greater than 5.

3.2 Dimensions of Pad

For strip and pixel readout methods, the pitch between strips or pixels directly affects spatial resolution. To investigate the effect of pad width on spatial resolution, resistive anodes with pad dimensions of 6 mm × 6 mm, 8 mm × 8 mm, and 10 mm × 10 mm were fabricated and tested using an X-ray machine with a 40 µm slot. A composite two-Gaussian model was used to fit the count distribution, as shown in Figure 7 [Figure 7: see original paper]. The spatial resolution is calculated as:

$$\sigma = \sqrt{g \cdot \sigma_S^2 + (1-g) \cdot \sigma_B^2}$$

where σ is the composite spatial resolution, σ_S is the signal component, σ_B is the background component, and g is the signal fraction [14].

Table 1 summarizes the spatial resolution for different pad widths. The results demonstrate that smaller pad widths yield better spatial resolution. However, for a given detector size, smaller pad widths also require more readout channels. Therefore, pad width selection should represent a compromise between spatial resolution requirements and electronics channel count based on specific application needs.

3.3 Nonuniformity of Pad Surface Resistivity

Nonuniformity of pad surface resistivity represents another critical factor affecting detector performance. Figure 8 [Figure 8: see original paper] illustrates

the influence of nonuniformity on imaging performance through simulation. To model this effect, a single pad was divided into four quadrants, each with a constant offset from the nominal pad surface resistivity. For example, in Figure 8(a), offsets of +5%, -5%, +5%, -5% (representing 10% nonuniformity) were applied clockwise from top-left to bottom-left. The results show that visual distortion appears when nonuniformity exceeds 30%, but remains negligible below 20%.

Experimentally, current thick-film resistor technology limits pad surface resistivity uniformity to 10%–50%. Figure 9 [Figure 9: see original paper] shows surface resistivity measurements for one resistive board, exhibiting approximately 20% nonuniformity except for one pad in the lower-left corner.

To quantify the nonuniformity effect, a scan along the x-direction in 5 mm steps was performed, with results shown in Figure 10 [Figure 10: see original paper]. The nonlinearity between setup position and measured position is less than 1%, indicating that a board with ~20% pad surface resistivity nonuniformity has acceptable impact on detector performance.

3.4 Imaging Result

Based on the optimization results, several resistive anodes were fabricated and tested in a detector prototype with 49 electronic channels. Figure 11 [Figure 11: see original paper] shows the imaging result for a mask pattern "AGE" with approximately 1 mm slot width. For this resistive anode board, $R_{\square P}/(R_{\square L} \cdot N) \approx 6$, the pad size is 6 mm × 6 mm, the strip size is 6 mm × 0.2 mm, and the pad surface resistivity nonuniformity is less than 20% (see Figure 9). The image was obtained using an X-ray machine positioned approximately 40 cm from the detector. The image quality is excellent, with sharp letter borders clearly resolved, and the prototype achieves a spatial resolution of 103.4 μm (Table 1).

4 Conclusion

The optimization of resistive anode parameters has been systematically investigated through experiments and simulations. To achieve good detector performance, the following design rules should be observed: the resistance ratio of pad to strip should exceed 5; the nonuniformity of pad surface resistivity should preferably be below 20%; and smaller pad widths yield better spatial resolution, with reaching approximately 105 μm for 6 mm pads.

In addition to these primary factors, experimental studies have identified other contributors to imaging performance. For instance, narrower strips benefit imaging quality, though current technology limits strip width to approximately 0.2 mm. Overall, detector performance results from the combined effect of all these parameters.

This study provides valuable guidance for determining resistive readout board

parameters and offers insights for detectors employing similar readout methods. With demonstrated spatial resolution around 110 μm, the resistive anode readout method shows promising application potential in MPGDs.

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References

5. M. Lampton et al., Review of Scientific Instruments, 50(9): 1093–1097 (1979)
6. XIU Qing-Lei et al., Chin. Phys. C, 37: 106002 (2013)
7. http://garfieldpp.web.cern.ch/garfieldpp/documentation/UserGuide.pdf, received 17th May 2015
8. WU Ling-Hui, Study of the offline calibration for the BESIII drift chamber and the beam test of a prototype, Ph.D. Thesis (Beijing: Institute of High Energy Physics, CAS, 2007) (in Chinese)

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