Finite Element Analysis of Electric Field Properties in Gas Electron Multipliers

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1. Introduction

Since the Micro-Strip Gas Chamber (MSGC) was first introduced in 1987, a large amount of effort has been invested in this new concept of gas avalanche microdetectors [1]. Improvements and variations of the original MSGC design have led to better detector performance. Among innovative devices have recently been proposed, Gas Electron Multiplier (GEM) is in spotlight [2,3].

The GEM uses the concept of electrodes separated by an insulator between them, resulting in intense electric field across a hole defined through the insulator. In other words, the GEM is a micro-hole array made on a copper clad laminate, known as one of material for the flexible printed circuit board. It is noted that the GEM geometry has a unique advantage that the charge multiplication region can be separate from the readout electrodes (*charge preamplification method*), which are usually very vulnerable to damage from sparking in the most of gas avalanche microdetectors.

The conventional GEM has a conically shaped hole in the insulating substrate made during wet-etching process [2]. Because of this shape, change of avalanche gain with respect to time was reported [3]. By using deep-etch x-ray lithography, Kim *et al.* developed almost cylindrically-shaped GEM hole in which the avalanche gain is free from the time instability [3]. This cylindrical shape of the GEM hole could also be achieved by the laser drilling as well as the plasma etching methods [4,5]. Due to the current innovative fabrication processes, a variety of GEM structures is possible.

The electric field strength and distribution within and around the GEM holes are very important parameters because those mainly affect on the GEM performance such as avalanche gain, time stability, and surface charging-up. To understand the GEM operation, to optimize the operational parameters, and to improve the design, finite element analysis (FEA) of the electric field has been carried out for various GEM structures and operation parameters. Based on the FEA results, the electron collection efficiency is estimated.

2. Methods

Figure 1(a) depicts a general configuration of GEM detector in cross-sectional view (for simplification, a unit cell is only sketched). The GEM is inserted between two electrode planes, the drift and collection planes. The GEM detector is typically operated in single-polarity mode, usually *electrons*. In view of electrons, this configuration gives three distinct regions corresponding to electron drift, multiplication, and collection. For a variety of GEM structures such as single conical, double conical, and cylindrical hole walls, *etc.*, the FEA has been performed by using a commercial computer code, Maxwell® (Ansoft Corporation, Pittsburgh, PA, USA). As the operation parameters, collection (E_C), drift (E_D), and GEM fields (E_{GEM} or ΔV_{GEM} per thickness) are considered.

For the reliable results, the FEA should be carried out under three-dimensional (3D) model, but which need a great amount of computational time. In this study, instead, cognizing an axis-symmetric property of the GEM structure, the electric field distributions have been analyzed in two-dimensional (2D) *rz* coordinates.

Electric field lines (or electron trajectories) are calculated by weighted-interpolation of the 2D data resulted from the Maxwell®. Key algorithm is that the current location is calculated by weighted-interpolation of four electric field vectors surrounding the previous location;

$$\mathbf{r}_n = \mathbf{r}_{n-1} + \frac{\mathbf{E}_{n-1}}{|\mathbf{E}_{n-1}|} \times \Delta , \qquad (1)$$

where $\mathbf{r}$ is a position vector and $\mathbf{E}$ is the 2D electric field vector. Δ is the step size.

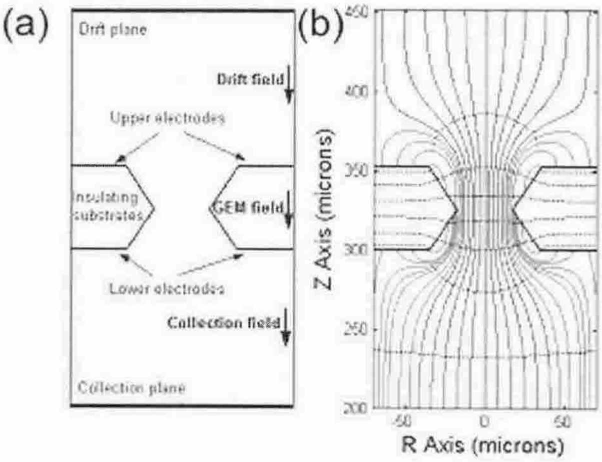

Figure 1. (a) A conventional layout of the GEM detector. (b) Electron trajectory map (or electric field lines) obtained from the field analysis, including equi-potential lines.

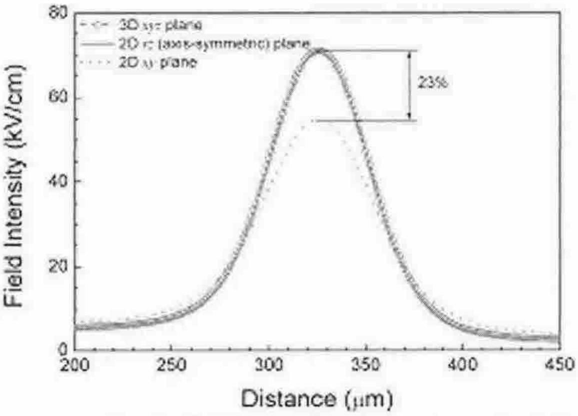

Figure 2. Electric field intensities for various simulation models.

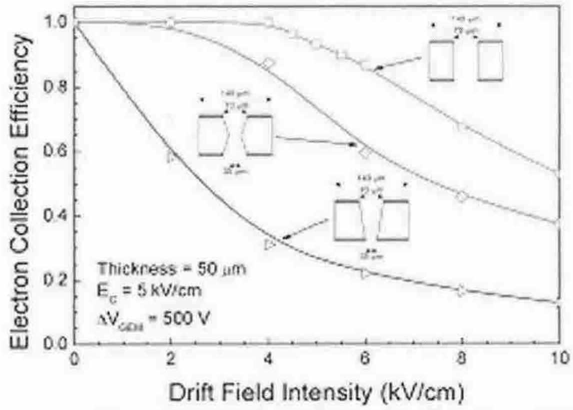

Figure 3. Electron collection efficiency of various GEM structures as a function of drift field intensity.

Assuming no electron scattering and gas diffusion, collection efficiency of electrons produced in the drift region by radiation interactions can be estimated by a calculation of fractional field-line transparency from the drift plane to the collection plane through GEM holes.

3. Results

As expected, modeling of the GEM in 2D *rz* coordinates and its analysis showed the same results that were obtained from the 3D FEA, while much saving computational time. As an example, field intensities through *standard* GEM holes (double conically shaped, polyimide substrate, thickness = 50 μm, hole pitch = 140 μm) in central axis under *standard* operation condition (E_C, = 5 kV/cm, E_D, = -2 kV/cm, ΔV_{GEM} = 500 V) are compared in Fig. 2. It is noted that the FEA in 2D *xy* coordinates, often used in previous studies, much underestimates. For the exact simulation results with 2D field analysis, modeling in 2D *rz* coordinates should be made.

Figure 1(b) illustrates electric field lines for the *standard* GEM operated at the *standard* condition. At this operation condition, all of drift field lines are well concentrated in the avalanche region and terminated on the drift plane, which means of 100% of electron collection. The equi-potential lines accomplished at this condition play a role of electrostatic lens for the drift field lines or electron trajectories.

Figure 3 shows an example of the calculated electron collection efficiency (ECE) for various GEM structures with respect to the drift field intensities. From this example, the ECE decreases as the drift field intensity increases. Moreover, the degradation of ECE is very affected by the structure, which implies that there is appropriate design for high ECE.

4. Summary

In this study, we analyze electric field properties in the GEM by using a finite element method. Compared with 3D simulation, modeling of the GEM in 2D *rz* coordinates is very efficient because of exact simulation results and much saved computational time. The ECE, which is an important measure designating the GEM performance, is estimated by calculating the fractional field-line transparencies. The ECE for various GEM structures and operational parameters are investigated and the results will be presented. This simulation work is very useful for the better design of the GEM.

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