A numerical investigation on the Discharges in Micromegas

Deb Sankar Bhattacharya, Raimund Ströhmer, Thomas Trefzger
University of Würzburg, Germany
Motivation:

- The discharge phenomena in gaseous detectors is a complicated process.
- There are several factors responsible for it.

- The fine structures in MPGDs may give rise to localised high electric field.
- Such regions may influence the discharge in direct or indirect ways.

- This study aims to develop a numerical model for discharge
- To apply it for Micromegas geometry
- A systematic field study on different Micromegas geometry
Using COMSOL Multi-Physics for discharge modelling in full 3-D for Micromegas.

It worked quite good in 2D-axis symmetric geometry for GEM

But, Micromegas is not 2D-axis symmetric...
Let's start by solving the field in a parallel plate:
Electric field (on the YZ plane)

The electric field is uniform throughout.

Along a line on the YZ plane, at X=Y= half pitch

The electric field is uniform throughout.
Building the discharge model
Building the physics model: (a simple approach)

Electrostatics (stationary solution)

\[ E = -\nabla V \]  
(electric field from given potential)

\[ \nabla \cdot D = \rho_v \]  
(for space charge)

\[ \frac{\partial C_i}{\partial t} + \nabla \cdot (-D_i \nabla C_i) + u \cdot \nabla C_i = R_i \]

\[ R_i = n_e u (\alpha - AC - X) \]

[Transport of Diluted species]

\( i \) is for electron and ion species
\( D_i \) = diffusion tensor in
\( C_i \) = number density.
\( u \) = electron drift velocity
\( R_i \) = production rate.

\( \alpha \) is Townsend coefficient
\( AC \) is attachment coefficient
\( X \) is for recombination

The transport parameters depend on the electric field, hence, to take into account the space charge effect, the coupling is important.

A full physical model can be found: RD51-Note-2011-005/14-03-2011, by P Fonte
However, the present model (diffusion assisted streamer) was well discussed in RD-51, Dec 2017
Solving it for parallel plates

Cathode at ‘-V’

Anode at ground potential

Gas Ar:CO2=70:30, penning 50
starts with 100 primary electrons

at -700 V

deB Sankar Bhattacharya, MPGD 2019, La Rochelle, 5-10 May 2019
Deb Sankar Bhattacharya, MPGD 2019, La Rochelle, 5-10 May 2019

starts with 100 primary electrons

number of electrons

at -740 V

time (ns)

starts with 100 primary electrons

10000

9000

8000

7000

6000

5000

4000

3000

2000

1000

100

10

10^{-1}

1

10

×10^{3}
Deb Sankar Bhattacharya, MPGD 2019, La Rochelle, 5-10 May 2019

at -760 V

starts with 100 primary electrons

time (ns)

number of electrons

$\times 10^3$
Deb Sankar Bhattacharya, MPGD 2019, La Rochelle, 5-10 May 2019

starts with 100 primary electrons

number of electrons

\( \times 10^3 \)

10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
100
1
10

time (ns)

at -780 V
Deb Sankar Bhattacharya, MPGD 2019, La Rochelle, 5-10 May 2019

starts with 100 primary electrons

number of electrons

time (ns)

at -800 V

starts with 100 primary electrons

number of electrons

time (ns)

at -800 V

Deb Sankar Bhattacharya
Deb Sankar Bhattacharya, MPGD 2019, La Rochelle, 5-10 May 2019

At -850 V

- Starts with 100 primary electrons
- The graph shows the number of electrons over time (ns) for different voltages (700V, 740V, 760V, 780V, 800V, 850V). The graph illustrates how the number of electrons increases rapidly with time as the voltage is applied.
starts with 100 primary electrons

**Figure 5.14.** Current oscillograms of static breakdown in methyl. Optical method. $E/l = 64.4$, $pd = 230$ Torr cm, $d = 0.8$ cm, $T = 90$ nsec $RC = 5$ nsec
How the space charge is changing the field; applied voltage -780V (~61 kV/cm)
How the space charge is changing the field; applied voltage -780V (~61 kV/cm)
How the space charge is changing the field; applied voltage -780V (~61 kV/cm)
How the space charge is changing the field; applied voltage -780V (~61 kV/cm)
How the space charge is changing the field; applied voltage -780V (~61 kV/cm)
How the space charge is changing the field; applied voltage -780V (~61 kV/cm)
How the space charge is changing the field; applied voltage -780V (~61 kV/cm)
With different primaries

- 780V-np100
- 780V-np10

Gain = 16K
Gain = 25K

For field screening
The effect of adding 1000 ppm of water (which is 4 % r.h.)

at 700 V

The graph shows the number of electrons over time for two conditions:
- **no water**
- **1000 ppm water**

The graph starts with 100 primary electrons and plots the number of electrons over time in nanoseconds (ns).
Ar:CO2=70:30

![Graph showing Electric Field (V/cm) vs. attachment (1/cm) with different conditions: attachment-noH20 and attachment-1000ppmH20. The graph indicates a decrease in attachment with increasing Electric Field.]
Ar:CO₂=70:30

Electric Field (V/cm)

townsend-noH₂O

townsend-1000ppmH₂O

10000 V/cm × 128 µm = 128 V
Solving this for Micromegas
18/45 Calendared-like:

The wires are taken as inter-penetrating

- Wire diameter 18 µm
- Edge to Edge 45 µm
- Axis to Axis 63 µm

Building the geometry:

- Drift gap = 200 µm
- Amplification gap = 128 µm
- Mesh voltage = -330 V
- Drift voltage = -350 V
• just below the wire

Result: Electric Field
Results: Electric Field

- mesh voltage = \(-330\) V
- max field = \(45.2\) kV/cm; average field = \(24.9\) kV/cm;

along a perpendicular line just below the wire (18-45)
Results:

probing the charge transport on a plane

The probing plane

mesh voltage = -330 V
drift voltage = -350 V
Results:

Transport of the electrons and avalanche.
Results:

Transport of the electrons and avalanche

![Image of electron transport and avalanche](image-url)
Results:

Transport of the electrons and avalanche

Time = 0.7 ns  Surface: $ne^*(ne > 0)$ (mol/m$^3$)
Results:

Transport of the electrons and avalanche.
Results:

Transport of the electrons and avalanche
Results:

Transport of the electrons and avalanche

Time = 2 ns  Surface: \( n_e(n_e > 0) \) (mol/m\(^3\))

\[ \text{mol/m}^3 \]

Total electrons, \( n \approx 54 \)
Results:

Time = 2.5 ns  Surface: $n_e^* (n_e > 0)$ (mol/m$^3$)

Transport of the electrons and avalanche
transport of the electrons and avalanche
Results:

Transport of the electrons and avalanche
Results:

The transport of the electrons and avalanche is illustrated in the figure. The surface plot shows the electron density ($n_e$) at $t = 10$ ns for $n_e > 0$ (mol/m$^3$). The color bar indicates the electron density range from 0 to $1.69 	imes 10^{13}$ (mol/m$^3$). The peaks at the center of the plot represent the avalanche effect.
Results:

Transport of the electrons and avalanche
**Results:** total electron production over time (mesh = -330 V)

![Graph showing electron production over time and current (nA) over time.](image)

(current or production rate)
mesh voltage = \(-330\) V

max field = 40.6 kV/cm; average field = 25.1 kV/cm;
Results: total electron production over time

![Graph showing number of electrons vs. time]

28-50 calendared, mesh voltage - 330 V

![Graph showing current vs. time]
Results: compare 18-45 VS 28-50
Field in some other Micromegas (around 30 µm wire diameter) is also studied

28/50 Calendared

30/70 Calendared

28/50 St. Woven

30/70 St. Woven
To order to generalise, all meshes are set to -540 V for this field study.

Amplification gap 128 µm

<table>
<thead>
<tr>
<th>geometry (µm)</th>
<th>Maximum (kV/cm)</th>
<th>Average (kV/cm)</th>
<th>$\varepsilon = (\text{max/ave})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>18/45</td>
<td>89.2</td>
<td>~40.5</td>
<td>2.2</td>
</tr>
<tr>
<td>22/56</td>
<td>88.3</td>
<td>~40</td>
<td>2.2</td>
</tr>
<tr>
<td>25/67</td>
<td>88.5</td>
<td>40</td>
<td>2.2</td>
</tr>
<tr>
<td>28/50</td>
<td>79.9</td>
<td>~40</td>
<td>1.9</td>
</tr>
<tr>
<td>30/70</td>
<td>84.2</td>
<td>~40</td>
<td>2.1</td>
</tr>
<tr>
<td>30/85</td>
<td>88.0</td>
<td>39.5</td>
<td>2.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>geometry (µm)</th>
<th>Maximum (kV/cm)</th>
<th>Average (kV/cm)</th>
<th>$\varepsilon = (\text{max/ave})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>18/45</td>
<td>112.0</td>
<td>~38.7</td>
<td>2.9</td>
</tr>
<tr>
<td>22/56</td>
<td>110.0</td>
<td>~38.0</td>
<td>2.9</td>
</tr>
<tr>
<td>25/67</td>
<td>109.0</td>
<td>~37.5</td>
<td>2.9</td>
</tr>
<tr>
<td>28/50</td>
<td>104.0</td>
<td>38.2</td>
<td>2.7</td>
</tr>
<tr>
<td>30/70</td>
<td>104.0</td>
<td>~37.2</td>
<td>2.8</td>
</tr>
<tr>
<td>30/85</td>
<td>106.0</td>
<td>~36.5</td>
<td>2.9</td>
</tr>
</tbody>
</table>

Calendared would be a better choice over woven for HV stability.
Conclusion:

• the occurrence and development of spark in 128 µm gap parallel plate is modelled
• dependence of humidity is shown in it
• regions with high electric field in different Micromeas geometry are identified
• a narrow voltage scan is performed to observe spark in 18-45 and 28-50
• influence of geometry is observed primarily; 28-50 and 18-45 show similar behaviour
Many many thanks to

Filippo Resnati
and the RD51 colleagues (specially Leszek, Fabio, Paul, Supratik)

for discussions and encouragement
The weaving is sometimes not symmetric (mesh thickness)

- Wire diameter 30 µm
- Edge to Edge 70 µm
- Axis to Axis 100 µm

The weaving amplitudes are different by 10 µm

rest of the geometry is same as the last one
The field through the centre of the hole

The average field is as expected

The field contour (on the YZ plane, at X=0)

The maximum field is $\sim 7\%$ higher than standard woven
if there is any defect on the mesh surface

- Wire diameter 30 µm
- Edge to Edge 70 µm
- Axis to Axis 100 µm

single point defect ~ 2 µm metallic
The field through the centre of the hole

The field contour (on the YZ plane, at X=0)

this remains as before

A very high field is localised around the defect
Electron Number

18-45
mesh = -350 V

Graph showing the relationship between electron number and time (ns).