Find eco-gas mixtures for a coupled readout MRPC

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17 Oct. 2019
Outline

• Background
• Study on signal generation of coupled readout MRPC
• Cosmic test of coupled readout MRPC prototypes
• Test status of MRPC3a using eco-gas
• Conclusion
MRPC3a for CBM-TOF wall

Timing performance for PID:

\[ m = p \sqrt{\frac{c^2 t^2}{l^2} - 1} \quad \Delta t < 80\text{ps} \]

High counting rate:

\[ \sim 30 \text{ kHz/cm}^2 \]

Structure of MRPC3a:

Glass: low resistive glass
0.7mm thick, 33cm*27.6cm

Strip: 27cm*0.7cm, 0.3cm interval, 32 strips

Gas gap: 8*0.25mm, two stacks

MRPC3a with low-resistive glass of \( \sim 10^{10} \Omega \text{cm} \):

<p>| | |</p>
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Efficiency</td>
<td>&gt;95%</td>
</tr>
<tr>
<td>Time Resolution</td>
<td>&lt;60ps</td>
</tr>
<tr>
<td>Cluster Size</td>
<td>\sim 1.6</td>
</tr>
</tbody>
</table>
Some drawbacks for MRPC3a

- Noise rate problem on the side strip near HV circuit

Method to apply HV. Only the side strip is shown. (32 strips in total)

<table>
<thead>
<tr>
<th>Side Strip</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>2946</td>
<td>1.22</td>
</tr>
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</table>

- Spraying colloidal graphite can be time-consuming and harmful for health.
Structure & Feature of Coupled Readout MRPC

The improvements:
1. Easier and more eco-friendly to produce
2. Reduce noise of side strip
3. Easy for impedance matching in requirement of occupation.
Why “Coupled Readout”?

Basis: Shockley-Ramo Theorem

\[ Q = -q \varphi_0(x) \]
\[ i = q \nu \cdot E_0(x) \]

Two contributions to readout signal:
1. Directly induced by moving charges, which can be described by S-R Theorem.
2. Induced by capacity coupling between HV and readout strips.

For charge in HV strip:
- Induced by moving charges in gaps, fit S-R Theorem.
- Flow from HV strip to the power source.

\[ \frac{dq}{dt} = N_0 e^{\alpha E vt} \psi_0 \nu E'_w + \frac{C_t}{C_{HV}} \frac{dQ}{dt} \]

\[ \frac{dQ}{dt} = N_0 e^{\alpha E vt} \psi_0 \nu E_w - \frac{Q}{C_{HV} R_{HV}} \]

\( E_w, \ E'_w, \ C_{HV}, \ C_t, \ R_{HV} \) are important for further calculations.
Maxwell 2D Simulation

<p>| | |</p>
<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>$E_w$</td>
<td>$\sim 700$ V/m</td>
</tr>
<tr>
<td>$E'_w$</td>
<td>$\sim 1.6$ V/m</td>
</tr>
<tr>
<td>$C_{HV}$</td>
<td>$189.3$ pF/m</td>
</tr>
<tr>
<td>$C_t$</td>
<td>$60.418$ pF/m</td>
</tr>
</tbody>
</table>

Simulation result

\[
\frac{dq}{dt} = N_0 e^{\alpha E v t} q_e v E'_w + \frac{C_t}{C_{HV}} \frac{dQ}{dt}
\]

\[
\frac{dQ}{dt} = N_0 e^{\alpha E v t} q_e v E_w - \frac{Q}{C_{HV} R_{HV}}
\]

\[
\frac{C_t}{C_{HV}} \sim 1/3
\]

\[
\frac{C_{HV} E'_w}{C_t E_w} \sim 1/100
\]
Cosmic Test System

Settings:
700, 702: MRPC3a, 5600V
701: Coupled MRPC, with and without resistors
Gas: Freon/iC4H10/SF6 90/5/5, 70ml/min
Threshold: 300mV
Triggering area: 20cm*5cm
Test Results: HV Scan

Efficiency:
Adding resistors decreases efficiency from 96% to 93%
Working point around 6000V

Time resolution:
Gets better with resistors.
Less than 100ps. (System $\sigma$)

Cluster size:
Decreases apparently with resistors.
Less than MRPC3a's level (~1.6)
Test Results at Working Point

**Multiplicity:**

- Without resistors
- With resistors

**Y position reconstruction:**

- Without resistors
- With resistors

**Noise on side strip:**

<table>
<thead>
<tr>
<th>Noise Rate (Hz/cm²)</th>
<th>MRPC3a</th>
<th>CMRPC</th>
<th>CMRPC-R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Side Strip</td>
<td>2946</td>
<td>4.00</td>
<td>2.00</td>
</tr>
<tr>
<td>Average Level</td>
<td>12.00</td>
<td>8.00</td>
<td>6.00</td>
</tr>
</tbody>
</table>

Coupled MRPC can solve the noise rate problem on the side strip.
Motivation on eco working gas

Global Warming Potential measures how much heat a greenhouse gas traps in the atmosphere up to a specific time horizon, relative to carbon dioxide.

European Union “F-gas regulation”:
- Limiting the total amount of F-gases that can be sold in the EU
- Banning the use of F-gases in many new types of equipment.
- Preventing emissions of F-gases from existing equipment.

Much uncertainty about the price and availability in the future

Eco-gas replacements:
- for Freon:

  \[
  \begin{align*}
    \text{FCC}_1 + \text{CH}_3 \text{CCH}_3 + \text{FSSSF} \\
    \text{GWP 1430} & \quad & \text{GWP 3.3} & \quad & \text{GWP 22800}
  \end{align*}
  \]

  GWP

  \[
  \begin{align*}
    \text{H}_2\text{C} = \text{C} - \text{C} - \text{F} & \quad & \text{H}_2\text{C} = \text{C} - \text{C} - \text{F} \\
    \text{HFO-1234yf (flam)} & \quad & \text{HFO-1234ze} \\
    \text{GWP 4} & \quad & \text{GWP 6}
  \end{align*}
  \]

  * One more carbon with a double bond, ideal substitute as refrigerant.
  Unknown about the performance of ionization.

  - Eco-gas mixtures
    He, CO₂, i-C₄H₁₀ …
Eco-gas Test Status

Settings: 3 MRPC3a counters
Gas: 70ml/min
a. Pure HFO
b. HFO/iC₄H₁₀ 95/5
c. HFO/iC₄H₁₀ 90/10
d. HFO/iC₄H₁₀/SF₆ 90/5/5
Threshold: 300mV

Dark current should be no more than 0.1μA to protect counters.

For gas c, fail to apply high enough HV for test. Other gas mixtures can execute the HV scan.
## Preliminary Test Results

### At working point:

<table>
<thead>
<tr>
<th></th>
<th>HV (V)</th>
<th>Eff</th>
<th>Noise (Hz/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HFO</td>
<td>7000</td>
<td>0.959</td>
<td>3.02</td>
</tr>
<tr>
<td>HFO/iso 95/5</td>
<td>6900</td>
<td>0.974</td>
<td>1.63</td>
</tr>
<tr>
<td>HFO/iso/SF₆ 90/5/5</td>
<td>7200</td>
<td>0.962</td>
<td>2.8</td>
</tr>
<tr>
<td>Std Gas</td>
<td>5500</td>
<td>&gt;0.975</td>
<td>1.22</td>
</tr>
</tbody>
</table>

\[ E_g: \sim 140 \text{kV/cm} \]

\[ E_g: \sim 110 \text{kV/cm} \]
Conclusion

• The principle of signal generation for Coupled readout MRPC has been studied. Coupled signal gives main contribution.

• Prototypes produced for cosmic test, and adding the resistors between HV strips and cable can help decrease the cluster size, multiplicity and noise level.

• However, more investigations on HV resistivity and producing process should be considered. More prototypes will be produced soon.

• Eco-gas test is still ongoing for more gas mixtures.

Thank you!