R&D on THGEM with Resistive Diamond-like Carbon Coating

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Motivation

**THGEM Charging-up effect**

Electric charge accumulated on dielectric material of THGEM, causing time-dependent gain variation.

**Possible solution**

MSGC surface coating with DLC (Diamond-Like Carbon) was employed to overcome surface Charging-up in 1998. Coating DLC on THGEM may help evacuating charges.

Time-evolution of the gain of THGEMs

Simulated Electron avalanche in THGEM

M. Alexeev et al 2015 JINST 10 P03026, The gain in Thick GEM multipliers and its time evolution
Coating DLC on THGEM

**Magnetron sputtering**

A Plasma Vapor Deposition (PVD) process, was used to produce DLC layer with controllable thickness and resistivity.

**THGEM parameters**

Sensitive area 5cm X 5cm, thickness 0.4mm, diameter 0.5mm, pitch 1mm, rim width 90μm.

**DLC-THGEM**

DLC layers of different resistivity were coated on a series of THGEMs (DLC-THGEM).

DLC thickness: 800nm. DLC resistance between THGEM copper electrodes: 68GΩ~6.7TΩ
Experimental Setup

Detector structure
DLC-THGEM detectors, drift gap 5mm, induction gap 4mm.

Setup
Detector chamber flushed with Ar/5% iC$_4$H$_{10}$. Cu target X-rays are collimated and filtered. Anode current was monitored with a picoammeter for gain monitoring. Fe55 X-ray also used in gain measurements.
DLC-THGEM Performance

- 22% Energy resolution to 5.9keV X-ray.
- DLC-THGEM achieved higher gain at lower voltage compared to normal THGEM.
- To achieve same gain, DLC-THGEM with lower resistance needs lower voltage.
DLC-THGEM Gain Stability

**Gain evolution along time**

- When continuously irradiated with 8keV X-ray 6mm diameter beam, DLC-THGEM anode current is very stable.
- Gain variation less than 5% irradiation rate up to 100kHz/mm² in 10 hours.
- No charging-up.

![Diagram of anode current along time of 1TΩ DLC-THGEM](image)

10kHz/mm² 8keV X-ray $V_{THGEM} = 810V$

Turn X-ray on

- **Gain of detector at different X-ray rate keep stable.**

- **Time evolution of gain of DLC-THGEMs with different resistance**

**Summary:**

- 1TΩ DLC-THGEM
  - $E_{drift} = 2kV/cm$
  - $E_{ind} = 1.5kV/cm$
  - $\Delta V = 810V$

- Normal THGEM
  - 680Ω DLC-THGEM
  - 1TΩ DLC-THGEM
  - 2TΩ DLC-THGEM
  - 6.7TΩ DLC-THGEM
DLC-THGEM Rate Capability

Gain at different X-ray irradiation rate

DLC-THGEM gain decreasing along X-ray rate.

Possible solution is Resistive THGEM without rim and no DLC in hole.

The avalanche charges drifting onto DLC will contributed to the current and voltage bias on DLC, which is relevant to irradiation rate.
Resistive THGEM

- Resistive THGEM (RTGEM) with DLC electrodes produced.

- Active area: 5cm X 5cm, thickness 0.4mm, diameter 0.5mm, pitch 1mm, no rim.
- DLC thickness 100nm~800nm, resistivity 100MΩ/□~1GΩ/□.
2000 gain in Ar/5% iC$_4$H$_{10}$.

Short term gain evolution about few minutes and no long term gain evolution along time.

RTGEM gain decrease drastically with increasing X-ray rate. RTGEM with lower resistivity DLC shows better rate capability.
To improve RTGEM rate capability, we produced RTGEM with ‘fast grounding’ circuits connected to HV circuits.

Resistive THGEM with fast grounding gain dropped less than 5% at 25kHz/mm² X-ray.

Gain vs. 8keV X-ray rate

△V=840V

G₀~700
Resistive THGEM

Large area RTGEM (with fast grounding)

- Resistive THGEM Design: 20cm \( \times \) 100cm active area, DLC resistivity 100M\( \Omega \)/\( \square \).
- 3mm induction gap, 6.5mm drift gap. Readout with pads (80 pads, 5cm \( \times \) 5cm each).

✓ Easy for manufacturing, only two steps: coating DLC \( \rightarrow \) drilling holes.
Large Area RTGEM

Preliminary results

- Energy resolution to 8keV X-ray is 23% with Ar/5% iC$_4$H$_{10}$
- Gain is higher at where near gas intake.
- Gain uniformity ~12%.

- Gain vs. HV
- Spectrum of 8keV X-ray
- Relative gain $\Delta V=800V$, Ar/5% iC$_4$H$_{10}$
  - $\sigma$/mean=14%
  - Gas in
  - Gas out

- $E_{\text{Drift}}=1.5kV/cm$
- $E_{\text{Ind}}=2kV/cm$
- $V_{\text{RTGEM}}=800V$
- Ar/5% iC$_4$H$_{10}$
  - FWHM/peak=23%
**DLC RWELL**

**RWELL based on THGEM**

Single side THGEM coupled to a thin resistive layer or plate.

**RWELL based on THGEM**

Single side RTGEM coupled to DLC resistive readout PCB.
DLC RWELL

Preliminary results

- RWELL achieved induced signal gain of 7000 in Ar/5% iC$_4$H$_{10}$.
- RWELL with higher resistivity DLC on readout pad achieved higher gain but rate capability is worse.
**Summary & outlook**

1. **DLC-THGEM** shows no Charging-up effect. But gain decrease along irradiation rate.
2. **RTGEM** with DLC electrode were firstly introduced. RTGEM with fast grounding shows good rate capability.
3. **Large area RTGEM** (20cmX100cm) with fast grounding were firstly produced. Gain uniformity 12%.
4. **RWELL** by coupling a single side RTGEM to DLC resistive readout PCB firstly studied.

**Much more work to do**
- Optimization of DLC parameter
- Detector structure
- Working condition
- Test method
- Simulation works to understand detector behavior...
THANKS

THE END
Back up slides...
A Simplified Model of DLC-THGEM

- Simplify the THGEM hole with DLC coating into a DC series circuit.
- The internal resistance of the hole is assumed to be uniform (constant surface resistance).
- DLC-THGEM with RIM equivalent to RIM resistive partial pressure + no RIM THGEM
- Ignoring the effect of electric field changes on electron collection efficiency and transmission efficiency
- The avalanche gain only calculates the integral effect along the central axis of the THGEM hole
Current calculation (1)

- Resistance of DLC in hole: \( R = \int_0^1 \lambda dz \)
- When the avalanche charge input from a certain point \( z \), the circuit is equivalent as shown in the right figure
  - \( I_0 = \frac{HV}{R} \), \( R_1 = (1 - z)R \), \( R_2 = zR \), \( i_1 = \frac{R_2}{R_1 + R_2} i(z) \), \( i_2 = \frac{-R_1}{R_1 + R_2} i(z) \)
  - Current at point \( z' \): \( i(z') = I_0 + \theta(z' - z)i_1 + \theta(z - z')i_2 = I_0 + i_2 + \theta(z' - z)i(z) \)
  - When considering \( i(z) \) input from various points, the total current: \( I(z') = \int_0^1 [I_0 + i_2 + \theta(z' - z)i(z)] dz \)
Current calculation (2)

- \( I(z') = \int_0^1 [I_0 + (z - 1)i(z) + \theta(z' - z)i(z)]dz \)
- If \( i(z) = i_0 \) is constant (assume ion current), then \( I(z') = I_0 + (z' - 0.5)i_0 \)
- If \( i(z) = -i_e e^\eta (1-z) \) is the current generated by electron drift onto DLC, then \( I_e(z') \approx \frac{i_e e^\eta (e^{-\eta z'} - \frac{1}{\eta})}{\eta} \)
- DLC-THGEM hole potential distribution is determined by \( \lambda I_{tot}(z') \). Generally, the voltage bias at both ends is large, and the intermediate voltage bias is low.
- Wherein the anode end (z~0) voltage bias > cathode end (z~1) voltage bias.
The total voltage between THGEM electrodes is 1000V. The simplified model divides the DLC resistive layer in the THGEM hole into 10 segments of resistance \( r = r_1 = r_2 = \ldots = r_{10} \) in series, where \( r_1 \) is closest to the anode.

When there is no avalanche current input, the voltage drop across each resistor \( r \) is 100V.

Adjust the voltage drop on \( r_1 \) and \( r_{10} \) at the same time: increase \( \Delta V \) volt on \( r_{10} \), increase the voltage drop on \( r_1 \) by \( 2 \times \Delta V \).

ANSYS calculates the electric field and the electric field strength on the axis of the hole (Z interval: -1mm~1mm).
Results (1) Potential distribution in THGEM hole

The voltage in the DLC changes uniformly, and the avalanche charge adsorption is mainly concentrated near the THGEM hole outlet. The voltage at the THGEM opening changes faster than the hole center.

The voltage variation in the DLC is not uniform, and the avalanche electron adsorption is mainly concentrated in the THGEM hole outlet near the anode, and the cation adsorption extends to most of the pores. When the count rate is high, this effect prevents the electric field from further concentrating near the anode, causing the THGEM gain reduction along rate to become saturated.
Results (2)
electric field strength on the axis of the hole (Z interval: -1mm~1mm)

Simulation results:
Gain decreases exponentially with additional voltage bias $G \sim e^{-\alpha \Delta V}$
If additional voltage bias $dV \sim \frac{dI}{I}$, $\Delta V \sim \ln I \sim \ln L$ (L for luminoxity, irradiation rate) and $G \sim L^{-\alpha'}$
RIM effects

- The voltage bias of the RIM part of the DC circuit reduces the voltage applied to the THGEM hole, \( \Delta V_{\text{EFF}} = HV - \Delta V_{\text{RIM}} \Rightarrow G \propto e^{HV - \Delta V} \)

- Experimental results show DLC-THGEM without rim gain decrease faster along rate than DLC-THGEM with rim.