Development of high-performance DLC resistive electrodes for MPGDs

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On behalf of the resistive DLC collaboration
Motivation

Resistive materials based on Carbon loaded pastes have already widely used in MPGDs to suppress the discharges and reduce the damaging effects on MPGDs.

- Resistivity sometimes out of control in manufacture;
- Unable to make fine structures;
- Difficult to make conductive route on it precisely;
- Can not open opportunities for new micro-structures;

**New reliable resistive materials and preparation methods needed**
A solution: Diamond-Like Carbon (DLC)

**DLC is a type of amorphous carbon which contains both graphite structure (sp²) and diamond structure (sp³)**

- Robust and stable, excellent chemical and physical inertness
- Sub-micrometer thickness, easy to make fine resistive structures;
- Surface resistivity can be precisely adjusted by changing the sp²/sp³ ratio or element doping;
- Allow to make precise routes by using photolithography
- Easily extend to large area;
- ......

Diamond structure

DLC structure

Graphite structure
Pioneering DLC applications on MPGD

High resistivity (~$10^{14} \Omega/\square$) DLC was applied on the MSGC by GDD in 1996.

Resistivity DLC (~$M\Omega/\square$) was applied on the Micromegas by A. Ochi in 2013.

- Charging up removed;
- Rate capability greatly improved;

- $1M\Omega/\square$ achieved by Nitrogen doping;
- Precise resistive strips successfully made by lift-off technique;
Resistive DLC Collaboration

DLC based electrodes for future resistive MPGDs

Title of project: DLC based electrodes for future resistive MPGDs

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Hybrid Physical-Chemical Vapor Deposition (HPCVD)

- Can be Deposited by chemical reaction or magnetron sputtering (or together)
- Low deposition temperature, high bonding strength, high deposition rate
- Pure DLC, Cr, Cu are deposited by magnetron sputtering
- Hydrogen doped DLC (a-C:H) is deposited by graphite targets sputtering and hydrocarbon gas dissociating at the same time

A common and flexible method for DLC deposition
Deposition & Application of DLC resistive electrodes

- **Thin DLC**
  
  Low internal stress → Control the resistivity → μRWELL, MicroMegas

- **Thick DLC**
  
  Cover the rough surface → Control the resistivity → THGEM, RPWELL

- **New type of “DLC+Cu”**
  
  Manufacture precise circuit → Control the resistivity → New MPGDs

- **DLC as photocathodes**
  
  Photoelectric properties → B-doped, controlling the SP³ → PICOSEC MicroMegas
Thin DLC on APICAL

- Resistive DLC prepared by magnetron sputtering the high purity graphite targets
- Resistivity controlled by adjusting target power, deposition time, vacuum degree, and so on.
**Application 1**

**low rate µRWell with 2D readout**

The micro-Resistive WELL detector: a compact spark-protected single amplification-stage MPGD

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**μRWell detector’s idea**

- **Energy resolution:** $\sim 21\% @ 8\text{keV X-ray}$
- **Rate capability:** gain drop $<10\% @ 100\text{kHz/cm}^2$
- **Spatial resolution:** $<70\ \mu\text{m} @ 150\text{GeV/c muon}$

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Application 2

High rate $\mu$RWELL and MicroMegas

- 6300 for the RG
- 5800 for the SG_v2
- 7700 for the SG_v1
- 7000 for the DL

G. Morello, RD51 Mini Week, 12-Dec-2017

- High rate capability (>1MHz/cm$^2$)
- Very good position resolution and energy resolution
- No charging up effects anymore

More details in M. Iodice’s talk on this conference
Deposition & Application of DLC resistive electrodes

- **Thin DLC**
  - Low internal stress → Control the resistivity → μRWELL, MicroMegas

- **Thick DLC**
  - Cover the rough surface → Control the resistivity → Resistive THGEM, RWELL

- **New type of “DLC+Cu”**
  - Manufacture precise circuit → Control the resistivity → New MPGDs

- **DLC as photocathodes**
  - Photoelectric properties → B-doped, controlling the $SP^3$ → PICOSEC MicroMegas
Allow to make thick DLC (~800nm) which is able to fully cover the surface of FR4;

The surface resistivity of DLC can be adjusted from ~kΩ/□ to ~PΩ/□ to fit the requirement of different applications;
Application 1

Charging up “Free” THGEM

Coating a-C:H DLC on the rim and hole area

- Doping hydrogen by adding isobutane from 7sccm to 9sccm
  - Easily applied on the current THGEMs;
  - Charging up effect almost removed;

More details in G. Song’s talk on this conference
Application 2

Full resistive RWELL

DLC layer

Large scale resistive THGEM

active area $100 \times 20\text{cm}$
Deposition & Application of DLC resistive electrodes

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  - Low internal stress
  - Control the resistivity → μRWELL, MicroMegas

- **Thick DLC**
  - Cover the rough surface
  - Control the resistivity → THGEM, RPWELL

- **New type of “DLC+Cu”**
  - Manufacture precise circuit
  - Control the resistivity → New MPGDs

- **DLC as photocathodes**
  - Photoelectric properties
  - B-doped, controlling the SP³ → PICOSEC MicroMegas
**Advantages of “DLC + Cu”**

- Simplifying the manufacture process and improving the quality of resistive MPGDs
- Allowing precise printed circuit layouts on DLC resistive electrode thus realizing complex functions
- Expanding the capacity and applications of the MPGDs and opening the way for new MPGD architectures
Application

Fast grounding μRWELL

- Photolithography is applied on the copper on DLC to make precise grounding lines
- Detection efficiency of SG2++ is better than 97%
- Gain drop of SG2++ <10% @ ~10 MHz/cm²

G. Bencivenni et al., "The micro-RWELL layouts for high particle rate", submitted to JINST
Other potential applications

- **High-rate applications**
  
  Double-DLC Micromegas/μR WELL made by Sequential Build Up (SBU) technique

- **Low mass applications**
  
  Full resistive detectors, like GEM, μR WELL, THGEM, etc...

- **Fast timing applications in high rate environments**
  
  Fast timing MPGD (FTM)
Deposition & Application of DLC resistive electrodes

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Keys to obtain high QE for photocathode

- **Improvement of band structure**
  Boron doped DLC by magnetron sputtering deposition

- **Optimize the ratio of \( \text{sp}^3/\text{sp}^2 \) of DLC**
  Increasing the content of \( \text{sp}^3 \) by vacuum cathodic arc & pulsed laser deposition

- **Reducing the surface electron affinity**
  Surface treatment, hydrogenation of the DLC surface by MWPECVD technique
Deposition of pure DLC & B-C photocathode

1. Achieve specific vacuum degree by controlling the pumping time

Sample Clamping

Vacuum Pumping¹

<2x10⁻²torr

Sample Pre-treating

Sample Pre-treating

Deposition

Sputtering graphite target

Sputtering B₄C target

DLC film

B₄C film

Cooling in Vacuum

Samples taking down

Preparation pure DLC and B-C film on photocathode by MS deposition

1x10⁻⁴torr

C or B₄C target

MgF₂ in the device chamber

C or B₄C target
Deposition of ta-C photocathode

Vacuum Cathodic arc deposition (VCAD)

1. Sample Clamping
2. Vacuum Pumping
3. Injecting Argon
4. Arc discharge
5. Deposition
6. Samples taking down

Pulsed laser deposition (PLD)

1. Sample Clamping
2. Vacuum Pumping
3. Pulsed laser
4. High temperature ablation
5. Deposition
6. Samples taking down
Application on PICOSEC MicroMegas detector

The results of Normalized QE vs wavelength

More details in X. Wang’s talk on this conference
Summary & Outlook

Summary:
◆ Developed a manufacturing technique for high-quality DLC resistive electrodes for MPGDs by exploring different preparation methods and process parameters.
◆ Developed thin DLC on APICAL for μRWELL, thick DLC on PCB for THGEM, “DLC+Cu” on APICAL for new structure MPGDs, boron doped DLC and ta-C on MgF₂ for photocathode.
◆ Development of DLC resistive electrodes opens up enormous opportunities for innovative development and application of MPGDs.

Outlook:
◆ Developing the deposition of large area (> 40 cm × 100 cm) resistive DLC electrode
◆ Developing more MPGDs with new structure, such as fast grounding μRWELL, Full resistive μRWELL, Full resistive GEM, and so on.
Back up
Ion deposition

Ion assisted deposition

Filtered cathodic vacuum arc deposition

Pulsed laser deposition

Dynamic diagram of sputtering deposition

Magnetron sputtering deposition

- Low deposition temperature (<300 °C);
- High bonding strength and low internal stress
Hot wire CVD

Microwave plasma CVD

- Dissociation of hydrocarbon gas
- No graphite targets
- High deposition temperature (>300 °C)
- High deposition rate
- More sp³ structures
The resistance is greatly affected by the target current.

The smaller target current, the more uniform resistivity.

The resistivity tends to decrease with the increase of the target current and deposition time.

The greater thickness of the DLC, the smaller resistivity.
The higher vacuum degree, the lower resistivity
Better uniformity resistivity during higher vacuum
The resistivity reduced to about 1/3 after 5 hrs and keep stable
Maybe a good method to stabilize resistivity by heat treatment
Both hydrogen doping and nitrogen can significantly increase the resistivity of DLC, especially hydrogen.

The resistivity of nitrogen-doped DLC is unstable, which increases with the keeping time.