DLC layers for MPGDs

Rui De Oliveira

On behalf of the Resistive DLC Collaboration

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DLC based electrodes for future resistive MPGDs

**Title of project:** DLC based electrodes for future resistive MPGDs

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**Diagram:**
- LICP: Theoretical calculation and simulation
- USTC: Small DLC + Cu foils production
- KOBE: Production of large Size DLC + Cu foils
- LNF-INFN: Long-term stability and aging test
- CERN: Detector Production with DLC foils
Diamond like Carbon base material

- **DLC**
  - Diamond like Carbon

- **DLC++**
  - Polyimide 50um
  - 100nm Cr
  - 5um Cu

- **DLC+**
  - GEM Base material
  - 100nm Cr
  - 5um Cu

- **DLC++**
  - GEM Base material
  - Polyimide 50um
  - 100nm Cr
  - 100nm DLC
  - 5um Cu
Kobe Japan
B-sputter
4 m x 1m real

ESS
2.1 m x 400mm?

China USTC
1.2 m x 500mm?

1m x 0.6m foils 500Kohms/square target
"DLC+" adhesion test

Copper adhesion force estimation
100%  GEM Base material
50%  USTC 300 deg deposition
40%  ESS
30%  USTC

The DLC Value is always lower after copper removal (at USTC and ESS) by a factor of 4 to 10?
20 foils produced recently
- Really Good resistive value repeatability
- Signs of weak adhesion of Cu/Cr on DLC
- Problems on 3 foils over 20

“DLC+” : present adhesion is just at the acceptable level
STD uRwell production steps

1. **DLC**
2. **R/O**
3. **GLUE**
4. **‘Wellize’**

- Really simple construction
- Flexible
- Low cost
- Low mass < 0.15%X₀

Large µRwell detector
Like CMS GE21 module M4
120cm x 55cm
Different high rate $\mu$Rwell structures

**SG**
- 1"DLC+" with Silver or Cu evacuation Grid

**DF**
- 1 "DLC" with Drill and fill method

**SBU**
- 2 "DLC+" Sequential Build Up
Efficiency
Cluster size
Gain
Space resolution
Time resolution
Rate

0.4mm strip pitch

Efficiency: PSI χ, ArCO CF, 45/15/48, v.19/02/01

Gain: PSI χ, ArCO CF, 45/15/48, v.19/02/01

Space resolution

Time resolution

5.7ns

Rate Capability - Gain 5000 - v.19/02/01
Discharge studies

The $\mu$-R WELL discharge probability measured at the PSI, and compared with the measurement done with GEM at the same time and in the 2004 (same gas mixture - Ar:CO$_2$:CF$_4$, 45:15:40).

The measurement has been done in current mode, with an intense 270 MeV/c $\pi^+$ beam, with a proton contamination of the 3.5%.

The discharge probability for $\mu$-R WELL comes out to be slightly lower than the one measured for GEM.

Moreover its discharge amplitude seems to be lower than the one measured for GEM.

Ageing studies (on going)

$Q_{\text{total}}$ has been defined as the current spike exceeding the steady current level correlated to the particle flux (90 MHz on a $5\,\text{cm}^2$ beam spot size).

The discharge probability for $\mu$-R WELL comes out to be slightly lower than the one measured for GEM.

Moreover its discharge amplitude seems to be lower than the one measured for GEM.

**GOAL:**
Integrate a charge up to 6 C/cm$^2$

Slice test of $\mu$-R WELLs during RUN3 in the LHCb Muon APPARATUS under discussion

+ Material long term stability
Protections to survive overvoltage
Overvoltage means sparks → Possible voltage breakdown of materials and large local energy release → DOCA protection (Distance Of Closest Approach)

**Breakdown voltage**

<table>
<thead>
<tr>
<th>Material</th>
<th>Thermal conductivity W/mK</th>
<th>Melting Celcius</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass epoxy</td>
<td>0.2</td>
<td>200</td>
</tr>
<tr>
<td>PI</td>
<td>0.18</td>
<td>400</td>
</tr>
<tr>
<td>Copper</td>
<td>384</td>
<td>1085</td>
</tr>
<tr>
<td>Natural diamond</td>
<td>1350</td>
<td>700</td>
</tr>
</tbody>
</table>

Of course, dielectric strength are greatly impacted by impurities, dopants, structure, interconnected porosity, flaws and micro-cracks from thermal expansion mismatches.

First problem: DLC layer breakdown due to the voltage set by the spark.
- if DLC is damage by Voltage Breakdown → no spark control
  - Good DOCA cancel this problem

Second problem: electron/ion bombardment during spark
- bombardment → temperature rise due to joule effect → material evaporation → material condensation → current instabilities
  - Bombardment effects can be mitigated
    - avoid repetitive sparks → remove contaminants (dust, ions from chemicals).
    - choose high melting temperature materials to lower the evaporation
  - choose good thermal conductivity & thicker layers materials to cool the reaction
    - DLC value can reduce spark energy
DOCA to prevent DLC BV

A breakdown of the resistive layer means creating a low Ohmic channel in the layer.

Breakdown of the resistive layer → No effect on the resistive layer

0V → HV

R layer

Polyimide

Dielectric

No possibility to create a voltage breakdown

DOCA = 250 μm

13
Columns of 11 patterns → DOCA ranging from 0.1 up to 1 mm
-Single hole test
-DLC 60M-70M/Sqr
-4 columns of 11 patterns have been tested (A,B,C,D)
Observations

- Leakage current start at 800V in air!
  - We were expecting 650V air BV for a 50um gap (like GEMs)

- The current shape during overvoltage depends on DOCA distance
  - Smooth current increase with long DOCA → small material deposition after evaporation?
  - Sudden increase to uA with small DOCA → larger deposition?

- After 30 sec with 30nA in one hole we start to see voltage drop
  - After several session of 30s, it stabilize at 550V / 650V (0 current voltage)
  - No visible damages on any structures.
  - There is obviously electric signs of material deposition
  - Unfortunately it was impossible to count sparks

- Next step will be to look at the “sparks” current shape when operating above Air BV
  - We would like to study the single hole spark current shape and rate with a fast oscilloscope.
  - This is possible with DLC since we have time before damaging the device

- Preliminary results: with 60Mohms/Sqr DLC, the DOCA can be as low as 0.1mm without visible damages
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What is the energy released level during spark?

1 X

- **70M DLC → 4 strips fired**
  - fired area: 1.6mm diameter
  - \( C = C_1 + C_2 \)
  - \( C_1 = E_0 \times E_r \times A/d \rightarrow 2pF \)
  - \( C = C_1 + C_2 \rightarrow 4pF \)
  - \( E = \frac{1}{2} CV^2 \)
  - \( E = 0.5 \mu J \rightarrow \text{reference energy} \)
  - Smooth current increase in overvoltage

25 X

- **10M DLC → 25 strips fired**
  - fired area: 10mm diameter
  - \( C = C_1 + C_2 \rightarrow 100pF \)
  - \( E = 12.5 \mu J \rightarrow 25x \text{more energy} \)
  - High current spikes in overvoltage

1000 X for a 10cm x 10cm GEM
Possible explanation of the DOCA Test results?

- 0V
- HV
- spark
- 1.6mm fired area
- 1mm DOCA
- 0.1mm DOCA
Possible explanation of the DOCA Test results?

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Possible explanation of the DOCA Test results?

The spark energy comes only from the fired area capacitor.

We keep control.

The spark energy comes from the fired area capacitor + HV connection + cabling + power supply effects.

We lose control.

No overlap

Overlap

1.6mm fired area

1mm DOCA

0.1mm DOCA

0V

HV

BV of air

100nA

0nA

20

uA peaks
Possible explanation of the DOCA Test results?

0V

HV

spark

1.6mm fired area

1mm DOCA

0V

HV

spark

0.1mm DOCA

1.6mm fired area

The spark energy comes only from
the fired area capacitor
+ HV connection + cabling
+ power supply effects

We loose control

0nA

100nA

BV of air

uA peaks

We keep control

The spark energy comes from
the fired area capacitor

Preliminary conclusion
DOCA should be defined taking care of
the fired capacitor size and resistive grounding design.

→ Needs new DOCA tests for precise values
Production
Different $\mu$Rwell structures

$\mu$Rwell

- Single “DLC” layer

High rate detectors

SG
- 1”DLC+” with Silver or Cu evacuation Grid

DF
- 1 “DLC” with Drill and fill method

SBU
- 2 “DLC+” Sequential Build Up

10cm x 10cm $\mu$Rwell detector “study kit”
SG type: Silver/Cu Grid

- Simple construction
- Adjustable evacuation point density VS rate
- Needs precise DOCA
- Needs "DLC+" Foils
- Large size detector registration

DOCA:
- 0.25mm
- 0.1mm grounding line
- 0.6mm dead line
DF Type
Drill and Fill

- Simple construction
- Adjustable evacuation point density VS rate
- Needs simple DLC foils
- No problem for large size production

- Needs precise DOCA
- DLC to silver contact need to be improved

R/O

DLC gluing

Drill

Fill

‘Wellize’

DOCA: 0.25mm
0.2mm hole
0.7mm dead zone

12mm
0.7mm
**SBU type**
Sequential Build Up

- Extra Large DOCA
- Adjustable evacuation point density VS rate
- 100% compatible with STD PCB processes

- Needs DLC+ base material

**R/O**

**DLC+ Pattern Pads & Glue**

**Drill Plate & Etch**

**DLC+ Pattern Pads & Glue**

**Drill Plate & Etch**

’Wellize’

DOCA : 6mm
Different Resistive protection approach with Micro-Megas

**Medium rate detectors**
- Single layer screen printed

**High rate detectors**
- 2 layers screen printed resistors
- 2 "DLC+" layers → SBU

**Printed**
- 2 "DLC+" layers → SBU

**SBU**
- 20 LSBB
  - 50cm x 50cm
  - X/Y 1mm/1mm
  - 30M/Sqr sharing layer

**Mix**
- MIX “DLC” and screen printed
2 Printed layers

- Extra Large DOCA
- Accurate layers registration in large size
- No DLC needed
- High rate detectors
- Embedded Res should be less than 10KOhms/square
- Large pads only
- Low energy resolution

PCB

Coverlay gluing + drilling + via fill

Resistive paste resistors (10KOhms/square max)

Coverlay gluing + via fill + top resistive printing (100K max)

'BULKage'

DOCA: 10mm

5 ILC DHCAL
50cm diameter
pads 1cm x 1cm
5M/Pad

1cm x 1cm pad → Ok
There is space to create a 2 Mohms Resistor with 10K/sqr paste

1mm x 3mm pad → Bad result
There is no space to create a 2 Mohms Resistor with 10k paste
2 “DLC+” structure with SBU process
Sequential Build Up

- Extra Large DOCA
- Adjustable evacuation density VS rate
- No problem with layers registration
- Good energy resolution
- 100% compatible with STD PCB processes

Needs “DLC+”
MIX method

- Large DOCA
- Maximized evacuation density points
- Needs simple DLC foils
- No problem with large size
- Ultra high rate detectors

-the filling technic is not STD in PCB world

PCB

DLC Gluing
DLC pattern

Drilling

Coverlay
Silver paste fill

Coverlay

Res paste fill

'BULKage'

DOCA: 2mm
conclusion

• Simple DLC material
  • Ready for large size and high rate detectors
  • For some application we need to get better resistive uniformity

• We need to improve the “DLC+” materials (Cu adhesion)
  • Main goal is to propose solutions 100% compatible with industry STD processes
  • There is still work to be done to produce large sizes “DLC+” foils

• DOCA & “Energy Release” study should be continued to optimize protection
  • Fine study of currents during quenched sparks
Thank you
examples:

- ATLAS NSW
  Strips 100k/Sqr
  2m x 1m

- ILC TPC
  30cm x 15cm
  3mm x 8mm pads
  2M/Sqr sharing layer

- 20 LSBB
  50cm x 50cm
  X/Y 1mm/1mm
  30M/Sqr sharing layer

- 5 ILC DHCAL
  50cm diameter
  pads 1cm x 1cm
  5M/Pad

- 32 T2K upgrade
  40cm x 40cm
  1cm x 1cm pads
  500K/Sqr sharing layer

- 2 Demonstrator
  5cm x 5cm
  1mm x 3mm pads
  2R layers 30M/5M
  2R layers 60M/60M

- MIX DLC/Printed

- 2 Demonstrators
  5cm x 5cm
  pads 1mm x 3mm
  5 M/pad
  20M/pad
<table>
<thead>
<tr>
<th>Item</th>
<th>Details</th>
<th>$%$ of $X_0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 GEMs</td>
<td>$6 \times 5 , \mu m$ copper [0.7]</td>
<td>1.68</td>
</tr>
<tr>
<td></td>
<td>$3 \times 50 , \mu m$ kapton [0.7]</td>
<td>0.42</td>
</tr>
<tr>
<td></td>
<td>TOTAL:</td>
<td>2.10</td>
</tr>
<tr>
<td>1 Drift</td>
<td>$5 , \mu m$ copper</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>$50 , \mu m$ kapton</td>
<td>0.17</td>
</tr>
<tr>
<td></td>
<td>TOTAL:</td>
<td>0.52</td>
</tr>
<tr>
<td>3 Grid spacers</td>
<td>$3 \times 2 , mm$ fiberglass [0.008]</td>
<td>0.25</td>
</tr>
<tr>
<td>1 Readout board</td>
<td>$80 , \mu m$ strips: $5 , \mu m$ copper [0.2]</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>1536 pads: $5 , \mu m$ copper [0.85]</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td>$50 , \mu m$ kapton</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>$120 , \mu m$ fiberglass</td>
<td>0.62</td>
</tr>
<tr>
<td></td>
<td>$60 , \mu m$ epoxy</td>
<td>0.30</td>
</tr>
<tr>
<td></td>
<td>TOTAL:</td>
<td>1.28</td>
</tr>
<tr>
<td>1 Shielding</td>
<td>$10 , \mu m$ aluminium</td>
<td>0.11</td>
</tr>
<tr>
<td>2 Honeycombs</td>
<td>$2 \times 3 , mm$ Nomex</td>
<td>0.46</td>
</tr>
<tr>
<td>4 Fiberglass foils</td>
<td>$4 \times 120 , \mu m$ fiberglass</td>
<td>2.47</td>
</tr>
<tr>
<td></td>
<td>TOTAL:</td>
<td>7.19</td>
</tr>
</tbody>
</table>

**TOTAL**

$0.719 \% X_0$

*Table 1.1: Material in one GEM detector*
Micro Well with XY aluminum strip, Chrome drift

Conservative approach, copper is used in the place of avalanche discharges.
If we use only aluminum it makes 0.16 $%X_0$
DLC Resistive GEM

FTM process

"DLC+"

Kapton etch

Cu/Cr etch

Cu/Cr pattern

Minimizing distortions with sectored GEM electrodes


In progress
Waiting for good base material

"DLC++"

+ sand blasting

"DLC+

+ sand blasting

Figure 3: (a) - 3D model of the DLC-coated GEM; (b) - Cross section of the structure. Schematic not drawn to scale.
Resistive THGEM

- Kapton with DLC
- PCB
- Kapton with DLC
- Glue the 3 parts with prepreg
- Drilling like a THGEM
Resistive measurements

Probe calibration

• 7cm x 7cm square of DLC
  • lateral silver connection to create 1 Square

• Connect probe to Ohm-meter

• Compare probe measurement to silver connections measurement

• Error in the range of 5%

• We can directly read the value from the Ohm-meter

<table>
<thead>
<tr>
<th>DLC Film</th>
<th>Surface Resistivity (kΩ/□)</th>
<th>Surface Resistance From The Probe (kΩ)</th>
<th>Coefficient Factor</th>
<th>Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>359</td>
<td>345</td>
<td>1.041</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>386</td>
<td>364</td>
<td>1.060</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>403</td>
<td>380</td>
<td>1.061</td>
<td>5</td>
</tr>
</tbody>
</table>
Resistive LEM

- Quenching of discharges with resistive 50×50 cm² LEM:
- Made at CERN EP-DT-EF:
  - copper side facing readout anode
  - DLC on 50 μm APICAL polyimide film (250 MΩ/□)
  - same geometry as CFR-35 (ProtoDUNE-DP)
  - no rims, no gold plating on copper face.
- Tests in progress at CEA/Irfu.
- R&D will continue in collaboration with CERN.

Tests @ CEA/Irfu

Signal from 5.5 MeV alpha
Goal of resistive protections

- Make Sparks invisible
- Simplify detectors
  - Reduce the cost
  - Be large size compatible
  - Aim to use only industrial processes
- Keep best “existing” MPGDs features
  - Rate
  - Space resolution
  - Time resolution
  - Energy resolution
  - Mass