Resistive Detectors with Diamond-Like Carbon(DLC)

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17-12-2021

Outline

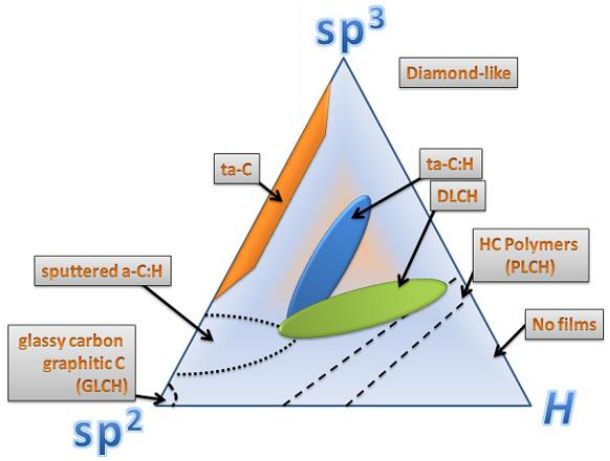
1. Introduction of the DLC

2. Applications of resistive DLC in gaseous detectors

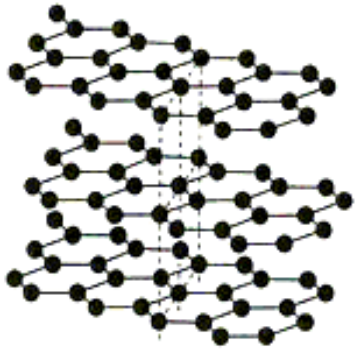
3. Summary

Introduction of DLC

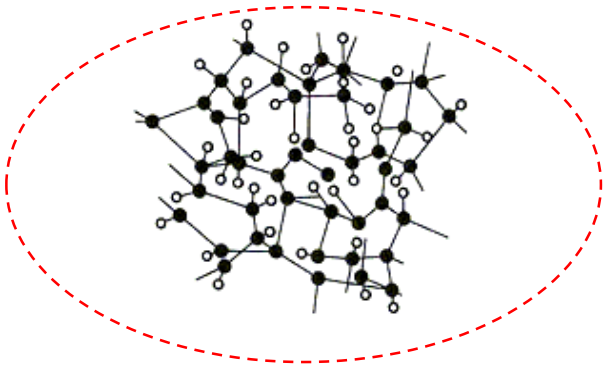
DLC is a type of amorphous carbon which contains both graphite structure (sp^2) and diamond structure(sp^3)



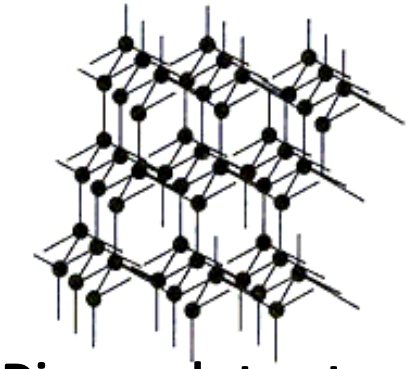
- ✓ *Robust and stable, excellent chemical and physical inertness*
- ✓ *Sub-micrometer thickness, easy to make fine resistive structures;*
- ✓ *Surface resistivity can be precisely adjusted by changing the sp^2/sp^3 ratio or element doping ;*
- ✓ *Allow to make precise routes by using photolithography*
- ✓ *Easily extend to large area;*
- ✓ *……*



Graphite structure



DLC structure



Diamond structure

Preparation of DLC by Magnetron Sputtering Method

Sample Baking → Sample Clamping → Vacuum Pumping

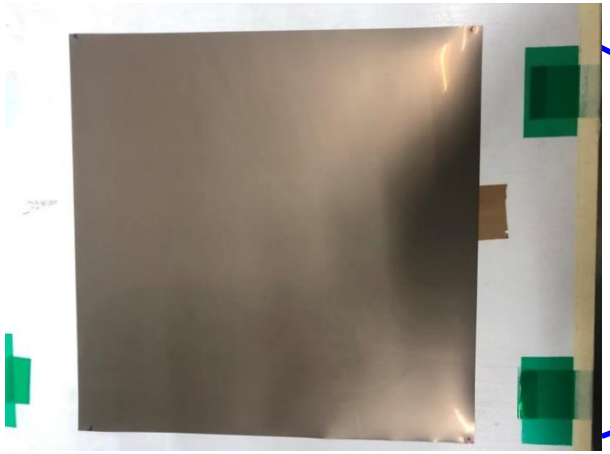
↓ Sample Pre-treating

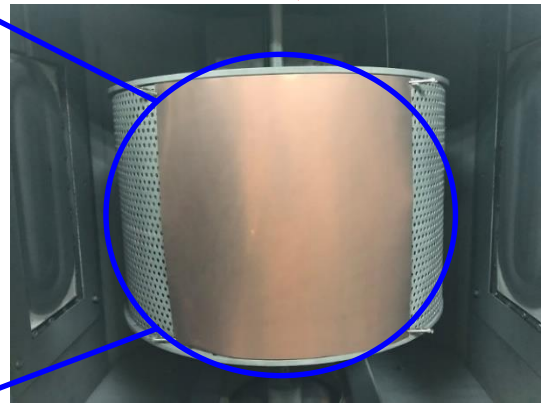
↓ Deposition

↓ Cooling in Vacuum

↓ Sample taking down

↓ Measurement





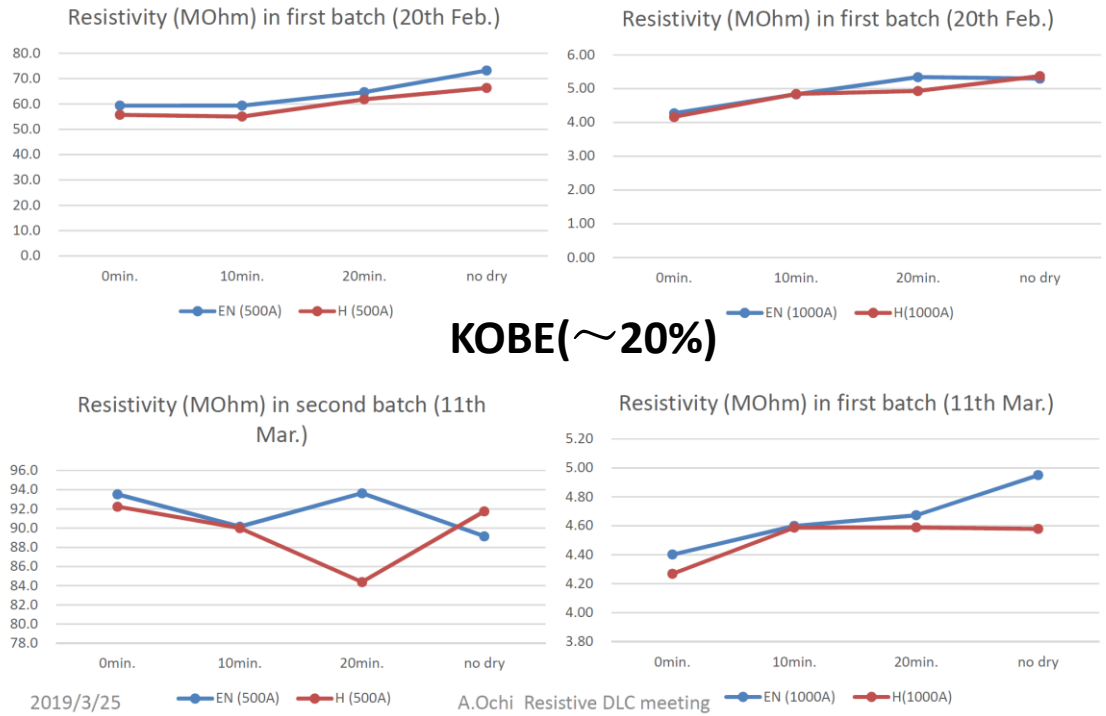
- ***Resistive DLC prepared by magnetron sputtering the high purity graphite targets***
- ***Resistivity controlled by adjusting target power, deposition time, vacuum degree, and so on.***

Passivation in air after sputtering

Data on this page comes from Resistive DLC Collaboration

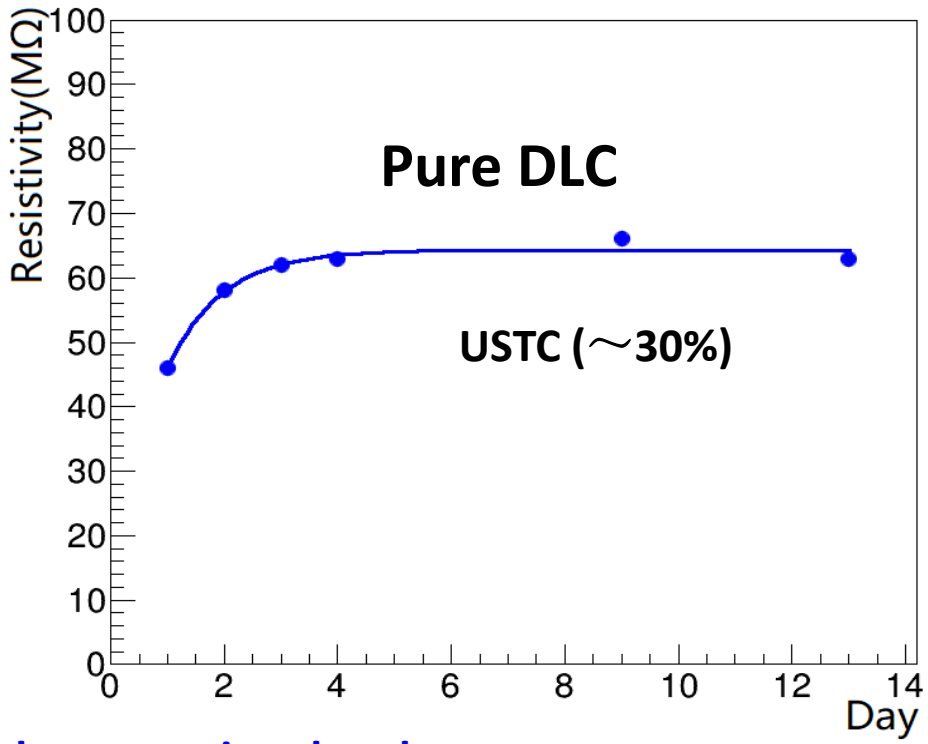
- To estimate the resistivity change before sputtering

Resistivity vs exposure time (very preliminary)



2019/3/25 A.Ochi Resistive DLC meeting 7

The resistivity of the a-C increased about 30% in three days, then became stable.



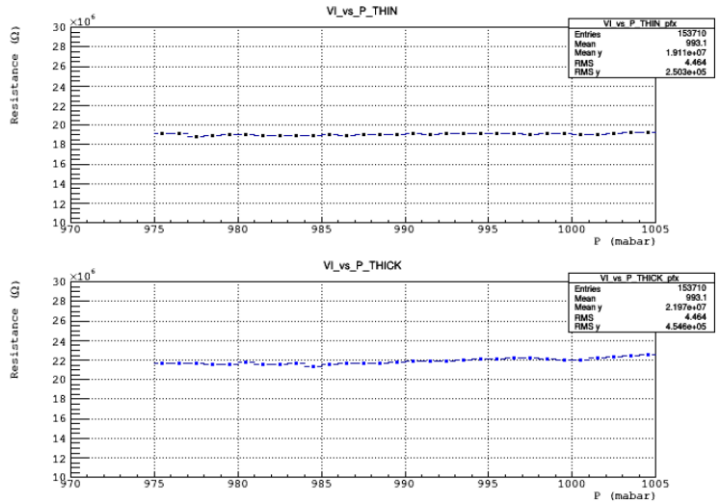
- DLC resistivity will increase in air after it was take out from the sputtering chamber;
- The test results from Kobe are more or less compatible with USTC results;

Stability in air

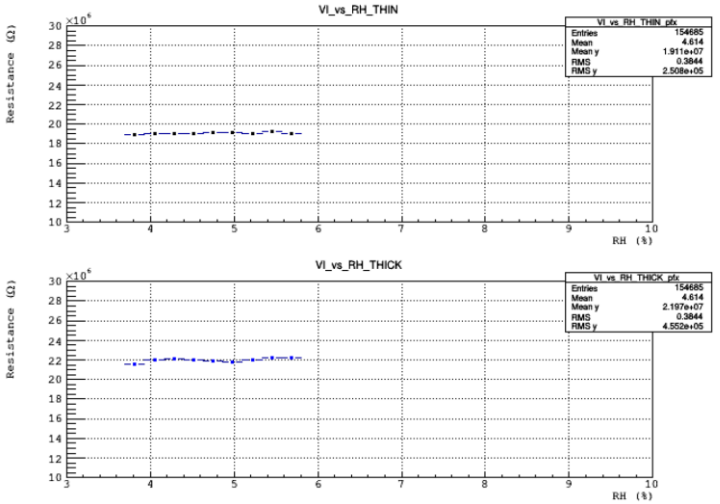
Data on this page comes from Resistive DLC Collaboration

- To make sure the DLC has long term stability in air

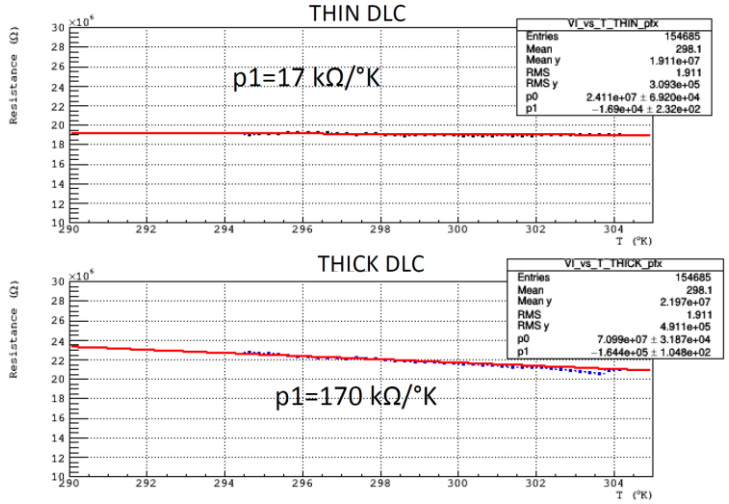
Resistivity .VS. Pressure

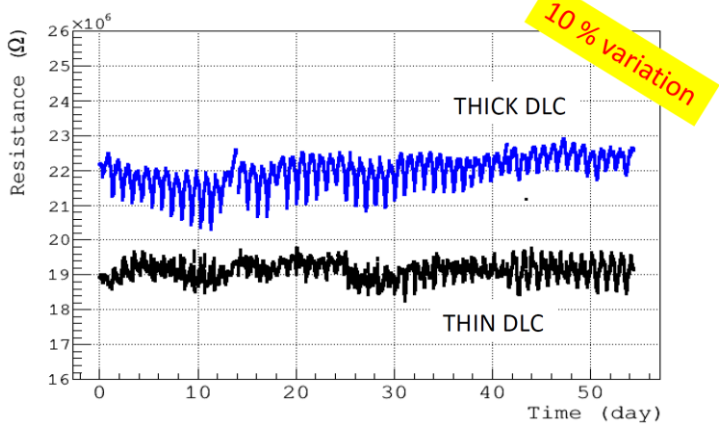


Resistivity .VS. Humidity



Resistivity .VS. Temperature





Conclusions:

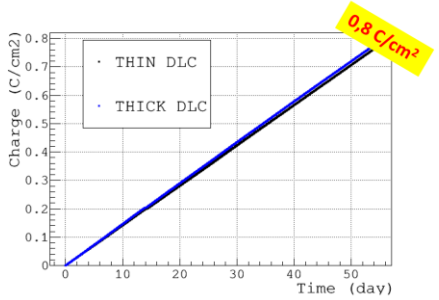
- The DLC resistivity is not sensitive to the pressure and humidity;
- The DLC resistivity will decrease when the temperature increase, more systematically measurement should be done in future;
- DLC has a very good long term stability in air;

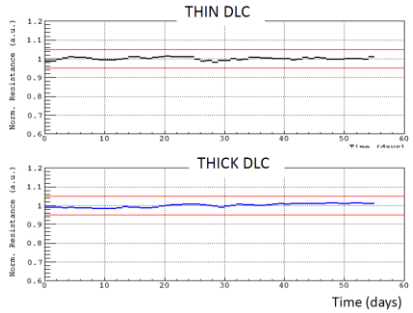
The aging measurement

Data on this page comes from Resistive DLC Collaboration

➢ To make sure the DLC is radiation hard

DLC stability under current drawing



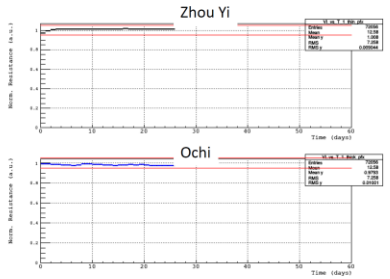


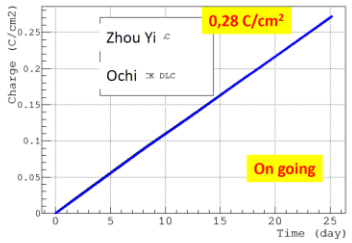
No effects obsserved after an integrate charge of ~ 1 C/cm²

DLC stability under current & X-ray

Similar setup of the previous measurement + X-ray gun irradiating the DLC surface

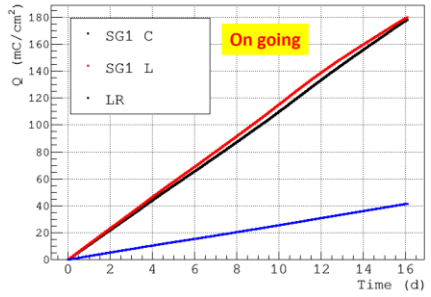
DLC foil (in black) produced by Zhou Yi
DLC foil (in blue) produced by Be- Sputter - Ochi

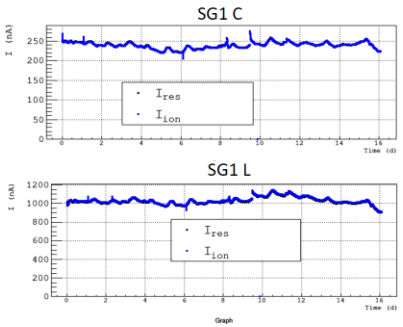




Detector aging: X-Ray LNF

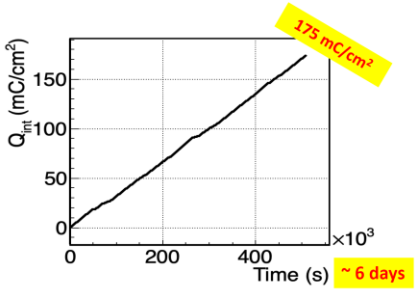
X-Ray gun- spot 50 cm² - Flux up to ~ 1,2 MHz/cm²

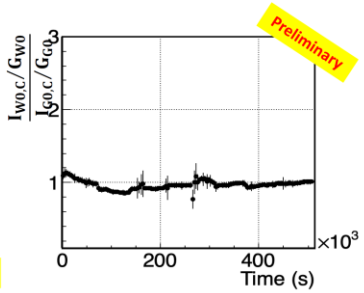




Detector aging: PSI

PSI TB, beam spot ~ 10 cm² Φ ~ 7 MHz/cm²

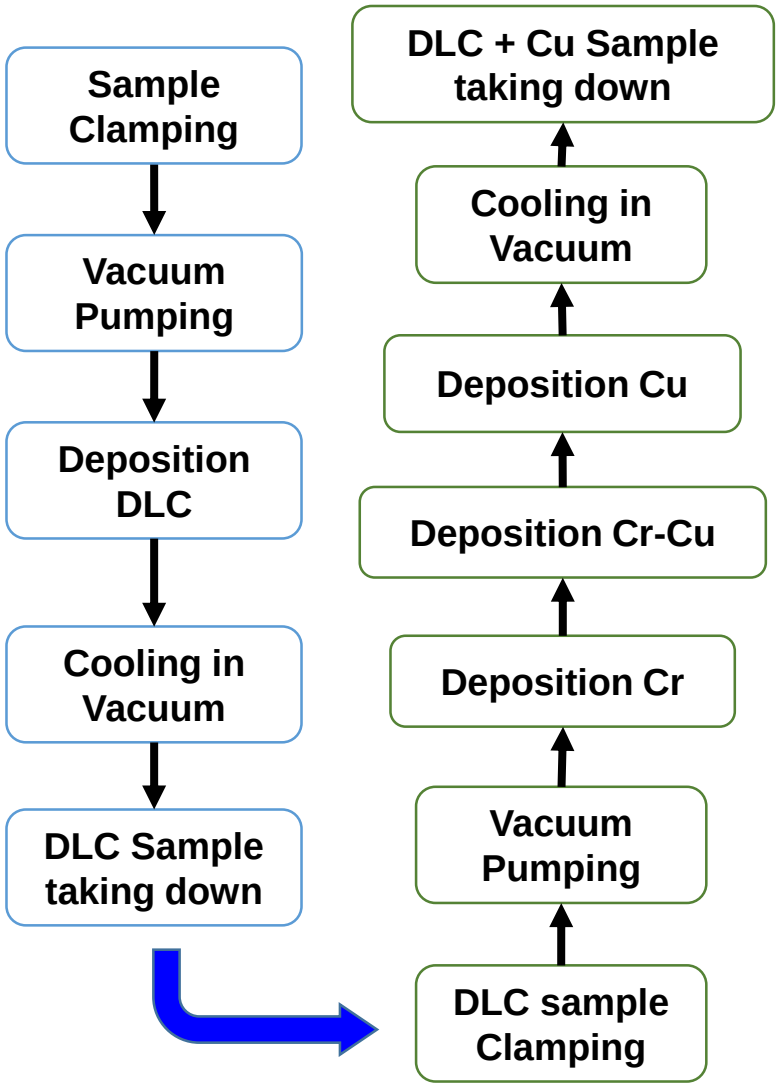




This result suggests the possibility to easily integrate in several (4-6) months a dose equivalent to 10 years of operation at the HI-Lumi LHCb .

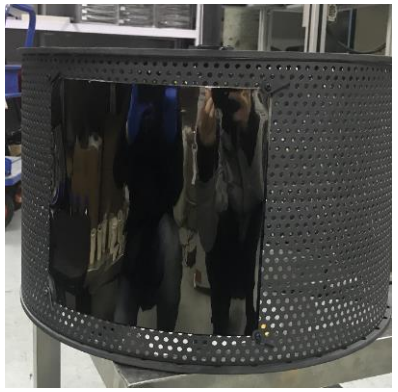
Conclusion: Currently looks good but we need longer time aging test to make sure it is good enough!

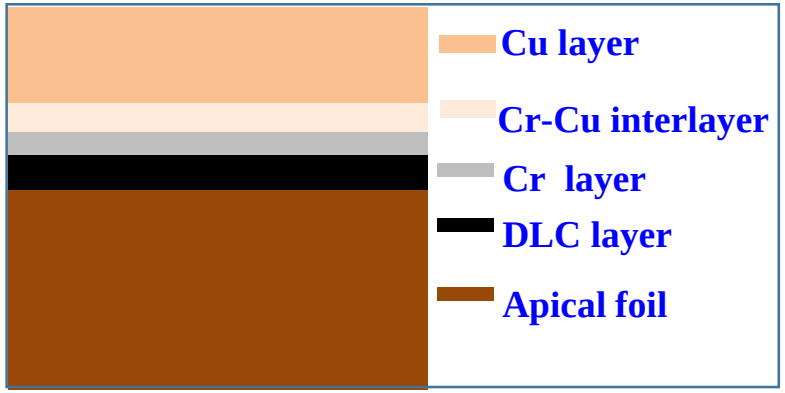
Preparation of DLC + Cu



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*

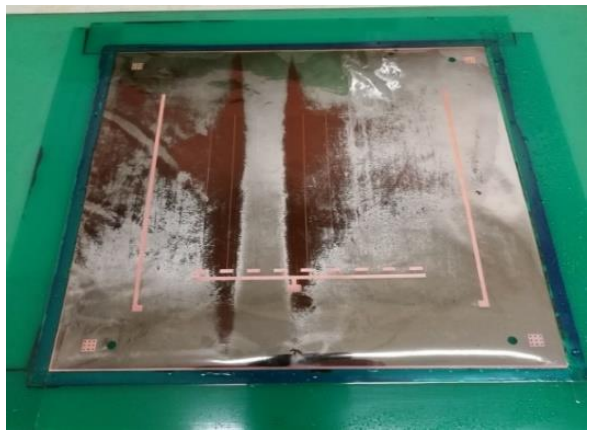


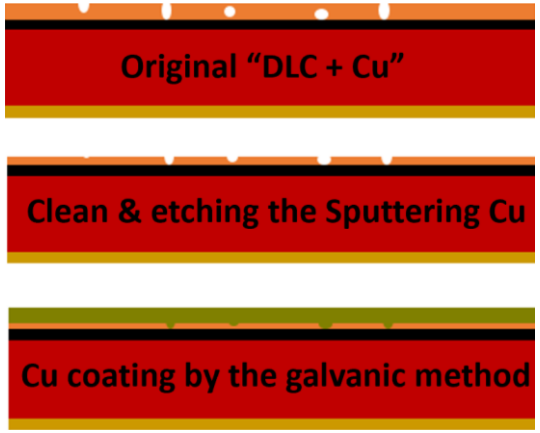


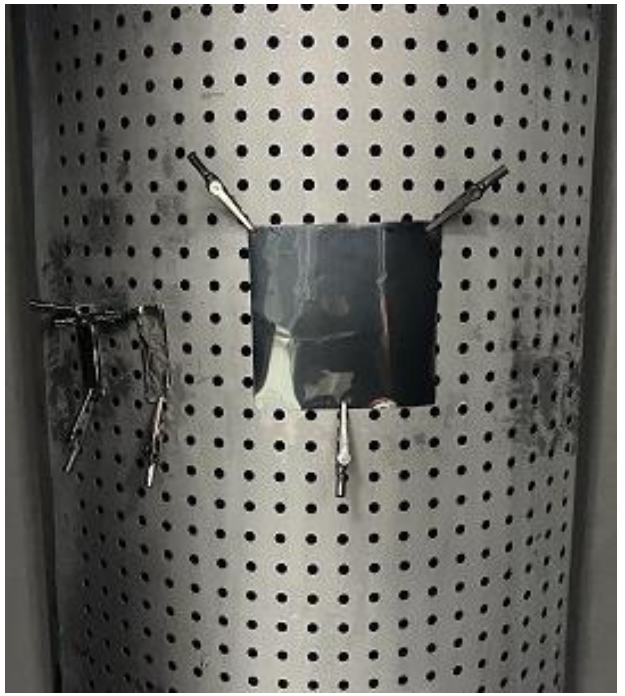
Problems found in DLC + Cu and the Solutions

Problems

1. Adhesion between Cr/DLC;
2. Etching of the Cr layer and Cr/Cu co-deposition layer;
3. Cavities inside the copper;
4. Resistivity decreasing after copper coating







Solutions

1. Increasing the roughness of the substrate and add DLC-Cr co-deposition layer;
2. Optimize the thickness of Cr and Cr-Cu co-deposition layer;
3. Extra Cu coating by galvanic method;
4. Calibrate the decreasing factor by covering the sample with aluminum foil;

1. Introduction of the DLC

2. Applications of resistive DLC in gaseous detectors

3. Summary

The First application of DLC in MPGD

In 1996， high resistivity DLC(R～$10^{14}\Omega/\square$) was firstly used in MSGC to remove the charging-up effect

ELSEVIER

Nuclear Instruments and Methods in Physics Research A 369 (1996) 328–331

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

Letter to the Editor

High rate operation of micro-strip gas chambers on diamond-coated glass

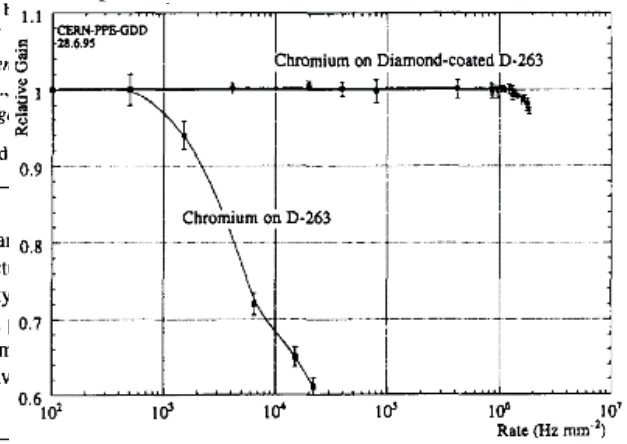
R. Bouclier[a], M. Capeáns[a], G. Million[a], L. Ropelewski[a], F. Sauli[a,*], T. Temmel[a], R.A. Cooke[b], S. Donnel[t]

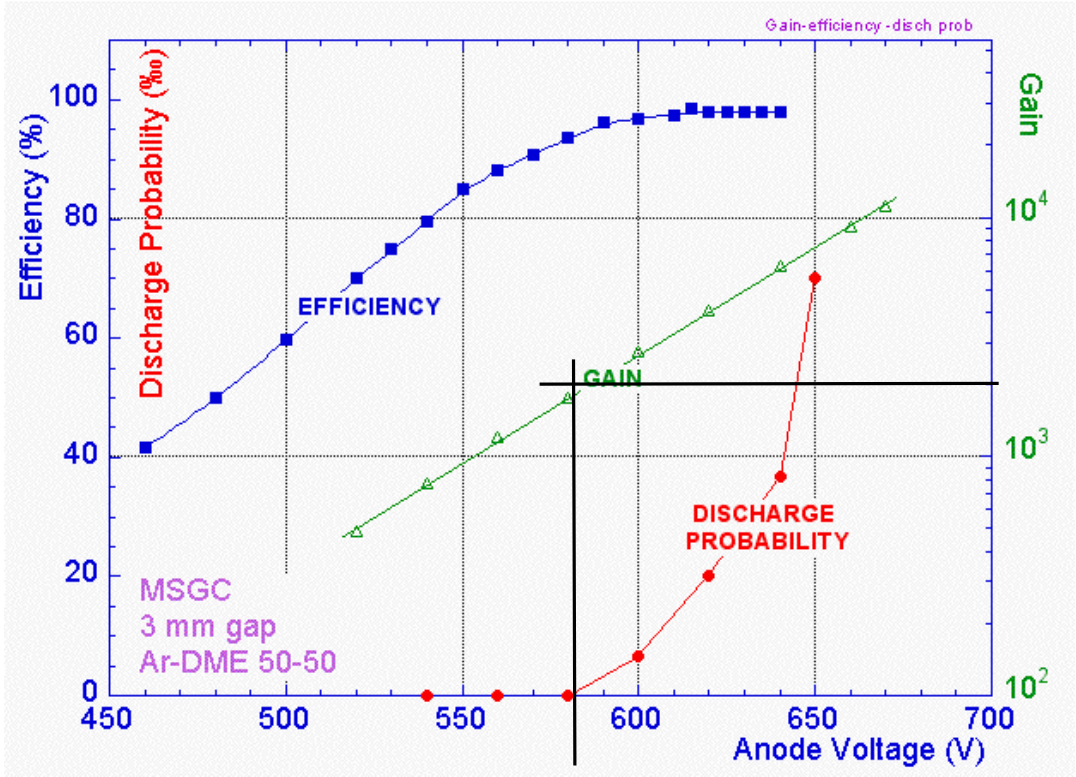
[a]CERN, Ge
[b]SURMET Corp.,
[c]IMT Masken und Teilung

Received

Abstract

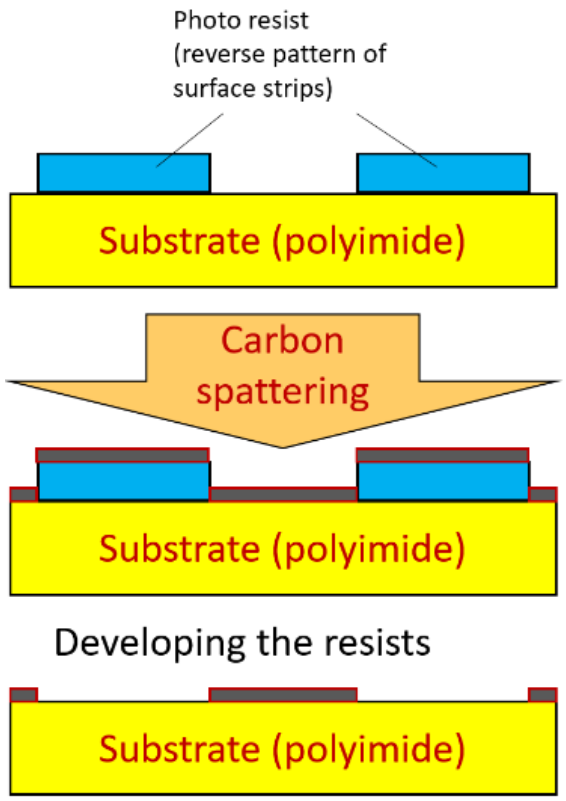
Very high rate operation of micro-strip gas chambers ca preliminary measurements realized with detectors manufact processing, with a diamond layer having a surface resistivity capability largely exceeding the one obtained with identical results are confirmed by long-term measurements, the dian with a moderate cost overhead, to use thin, commercially av production of gas micro-strip detectors.

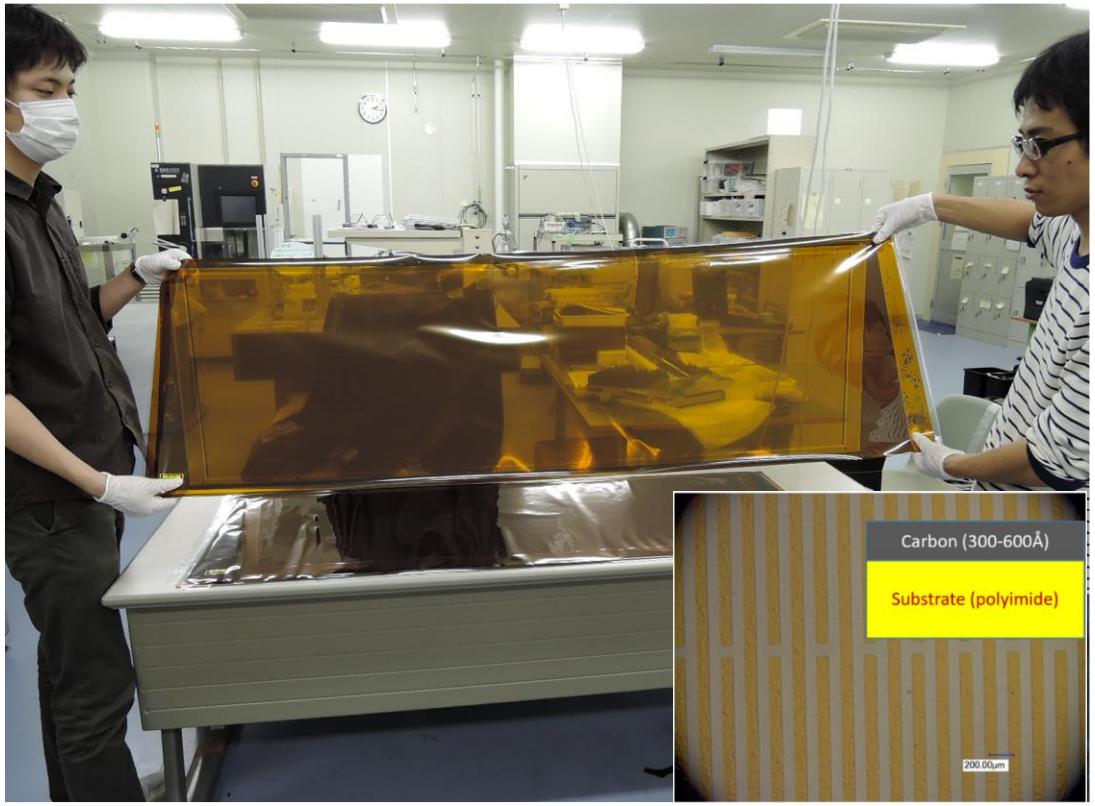


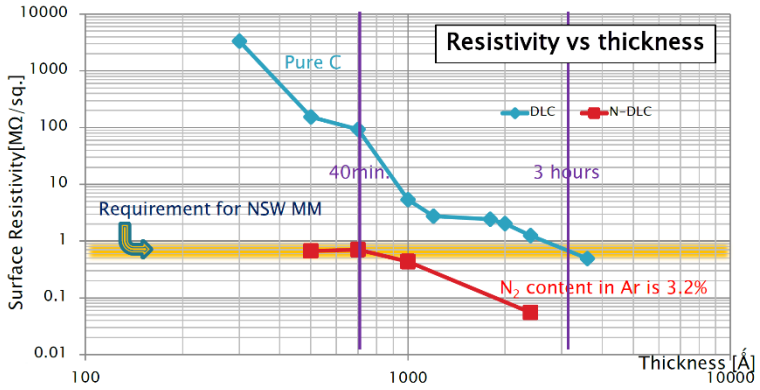


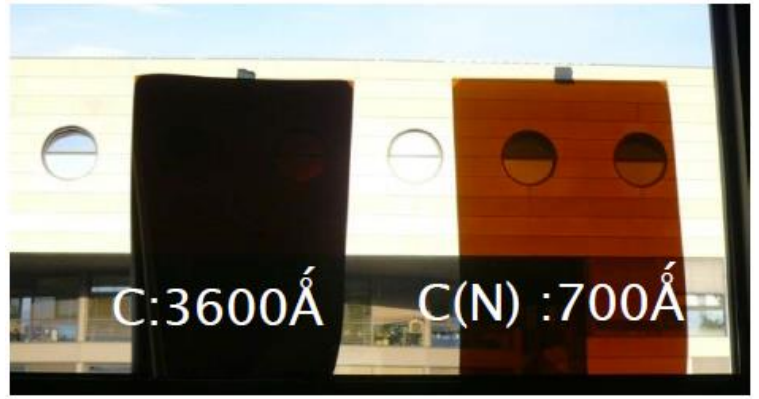
- × The resistivity of this DLC is too large, it can not be used as a resistive electrode;
- × This DLC is made by the low pressure plasma assisted CVD(LPCVD)， it is very difficult to precisely control the resistivity by using LPCVD.

The First Application of Resistive DLC in MPGD







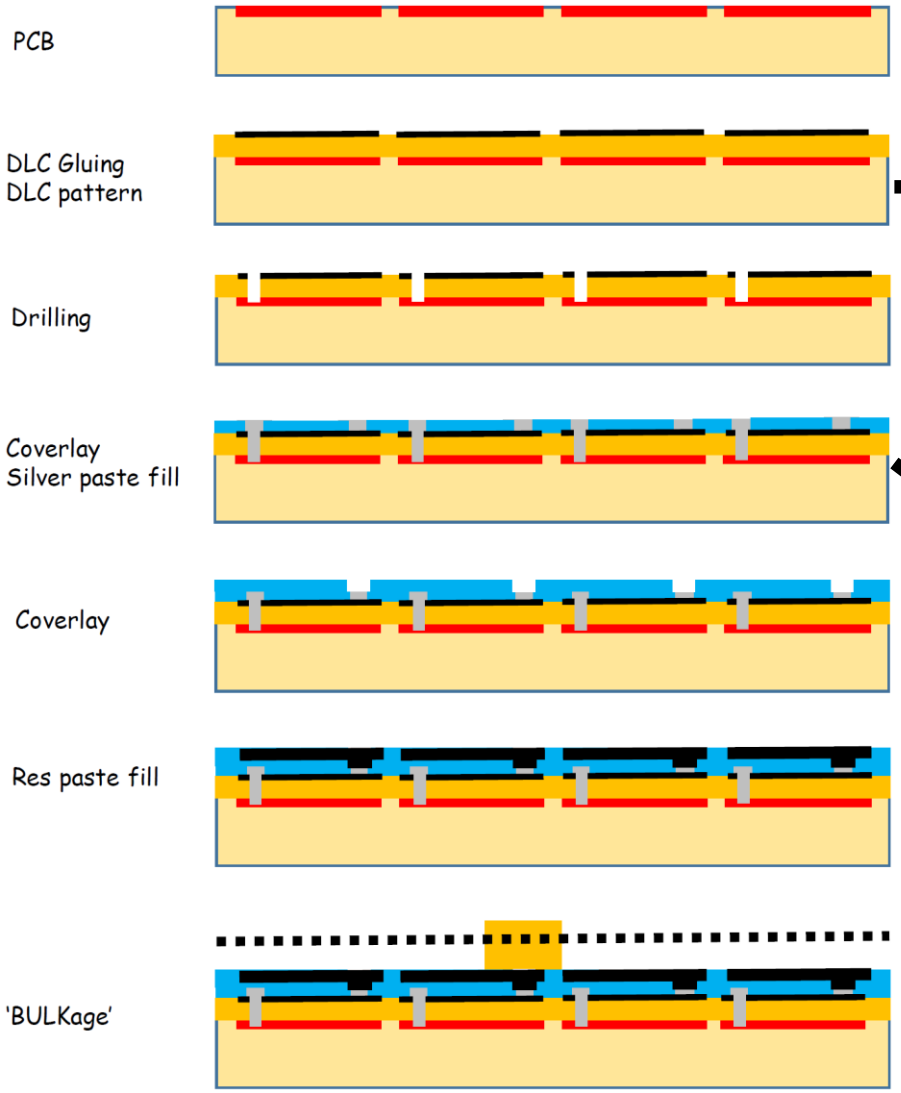


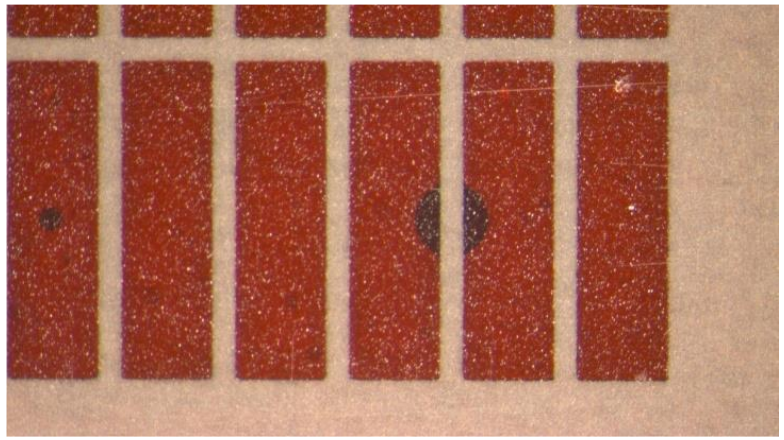
In 2013, Atsuhiko Ochi (collaborated with Be-Sputter) successfully made DLC strips with ~1MΩ/□ resistivity by using the magnetron sputtering method and lift-off technique.

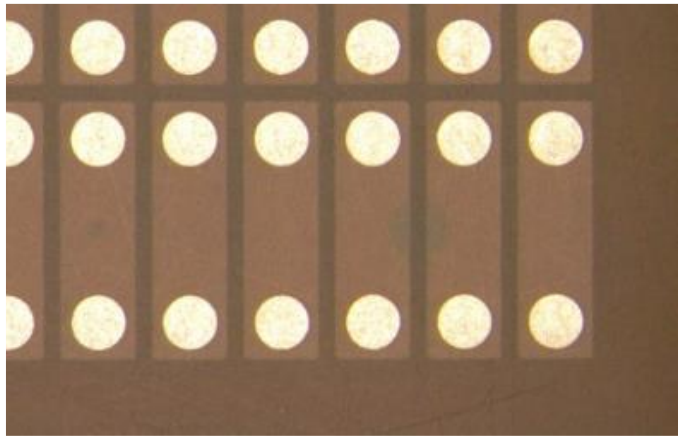
A.Ochi, New Small Wheel MicroMegas Mechanics and layout Workshop, 25-June-013

A.Ochi, RD51 mini week, 08-June-2015

Micromegas Made by MIX (DLC + Screen Printing) Method

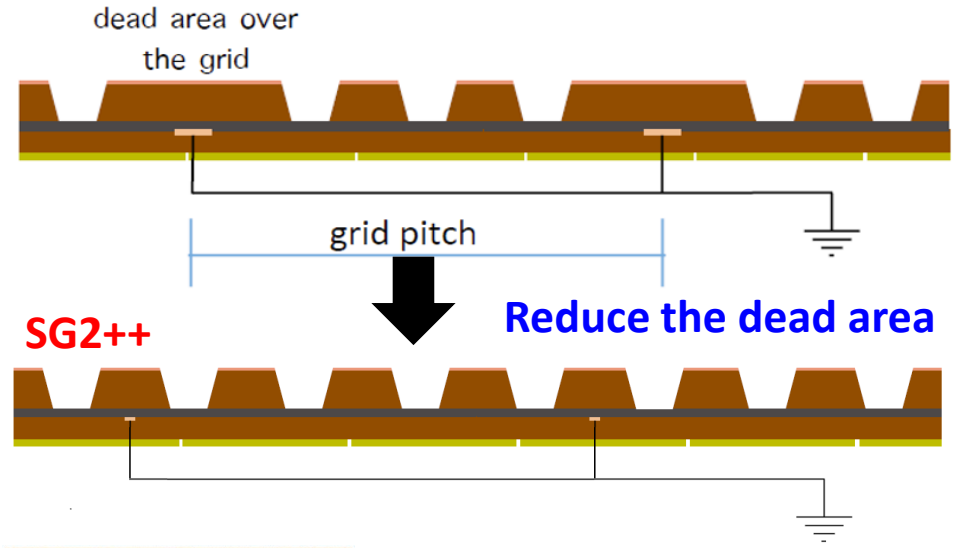




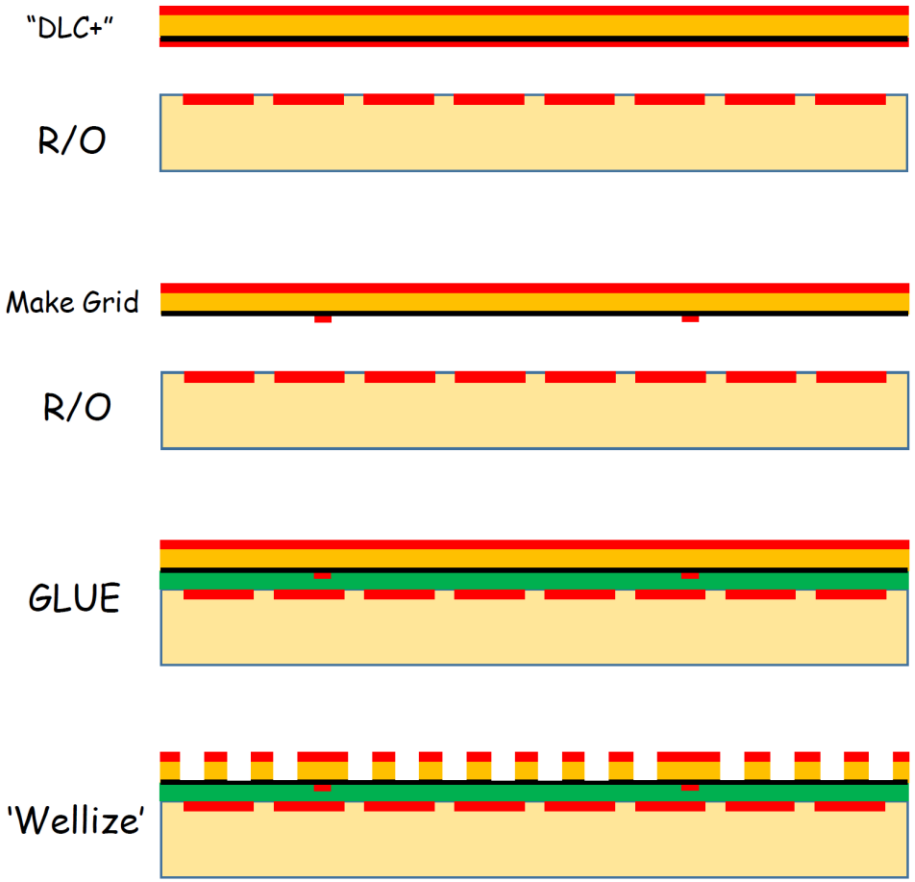


- Large DOCA (2mm)
- Maximized evacuation density points
- Needs simple DLC foils
- No problem with large size
- Ultra high rate detectors
- The filling technic is not STD in PCB world

µRWELL with Fast Grounding Lines under the DLC



- ✓ *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*



There are alignment problems when it goes to large area

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

R. De Oliveira, INSTR2020, 28-02-2020

μRWELL with GND Patterns on Top Surface

PEDF: Patterning , Etching , Drilling & Filling

Step1: Copper & APICAL etching, to make a big hole, with DLC on bottom.

Step2: Drill a small hole, the copper of the readout pad expose to air.

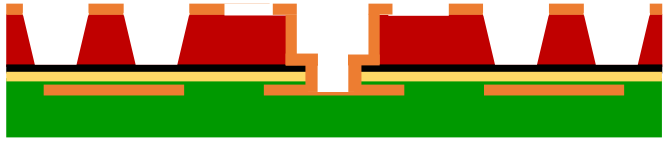
Step3: Use silver glue to connect the DLC to readout pad.

Step4: Make μRWELL structure and remove the copper around silver glue.

Different options of high-rate μRWELL

PEDP: Patterning , Etching , Drilling & Plating (The Best One)

DEP: Drilling , Etching & Plating



DEF: Drilling , Etching & Filling

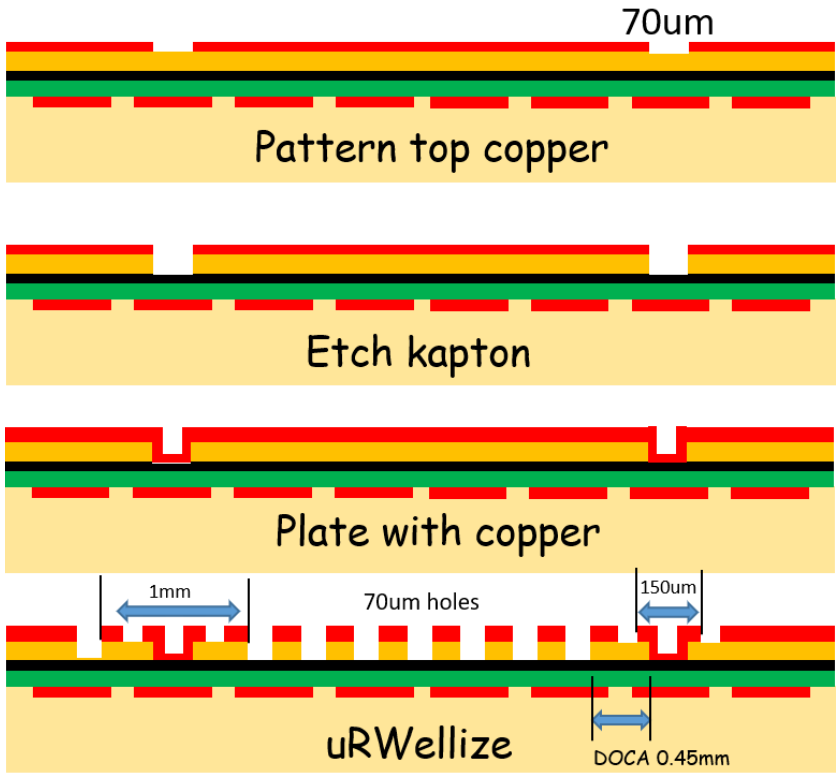
Four different types (PEDF , DEF , PDEF , DEP) of μRWELL PCB have been produced at CERN and transferred to USTC .

Advantages:

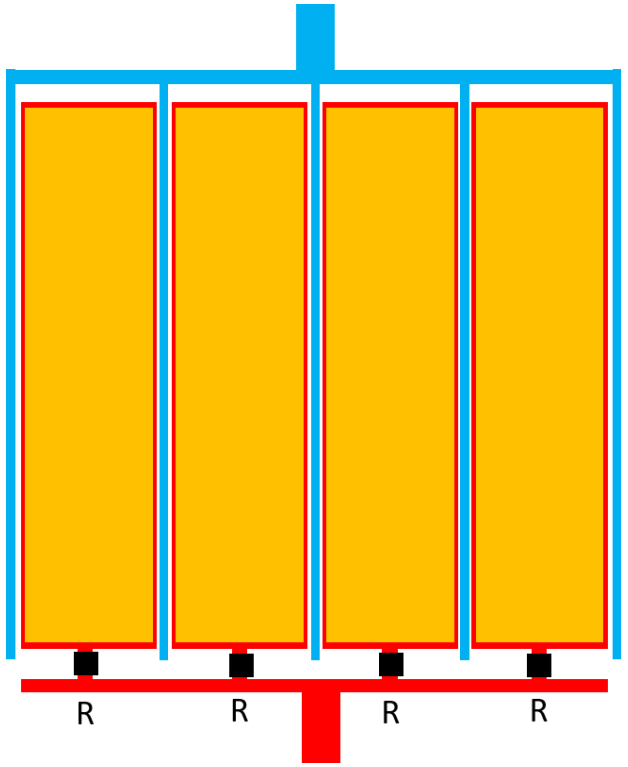
1. No copper-coated DLC needed, better resistivity control;
2. No alignment problems even goes to large area;
3. Larger contact area between DLC and silver glue, improving the connection.

µRWELL Made by the PEP Technique

PEP cross section



PEP top view



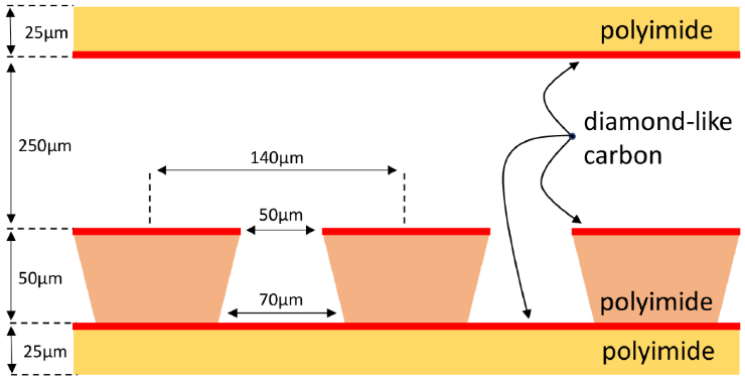
-Cu Connection to DLC through a 70um groove or a row of 70 um vias
-Top strip 150um
-Grounded electrode

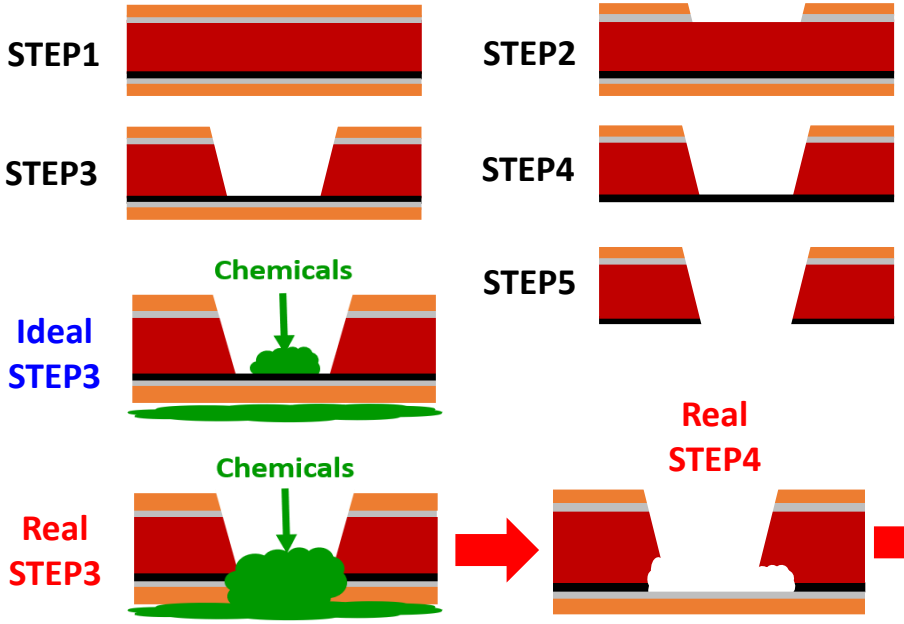
-Amplification Holes
-DOCA 0.45mm
-1mm from hole to hole

Top electrode connected to -HV
With or W/O Resistors

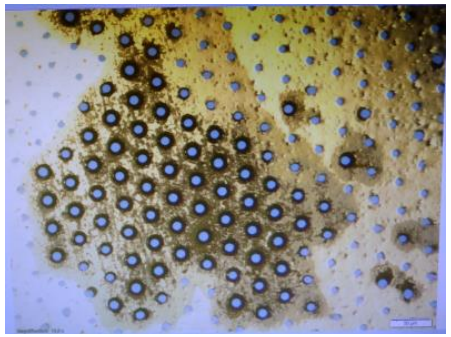
Any pattern can be created to connect the DLC , row of dots but also line.
No alignment problem for large size.
Do not need drilling with Z axis control (simpler than previous structures).

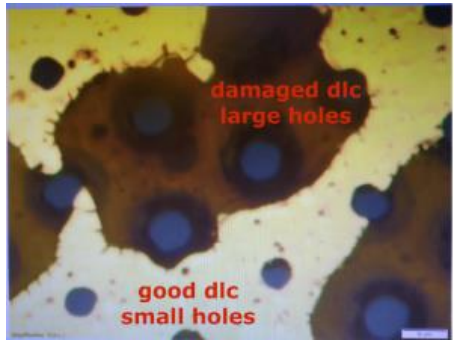
μRWELL-type FTM



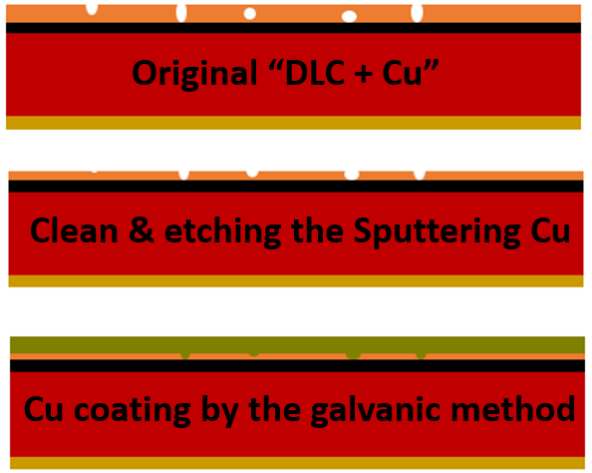


Problems





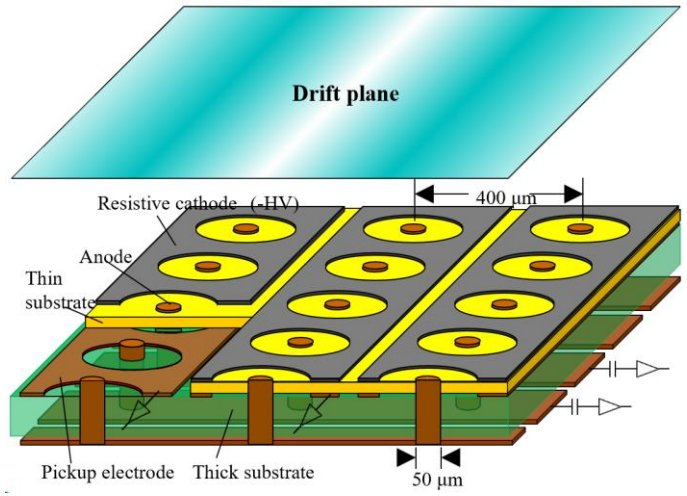
Solution

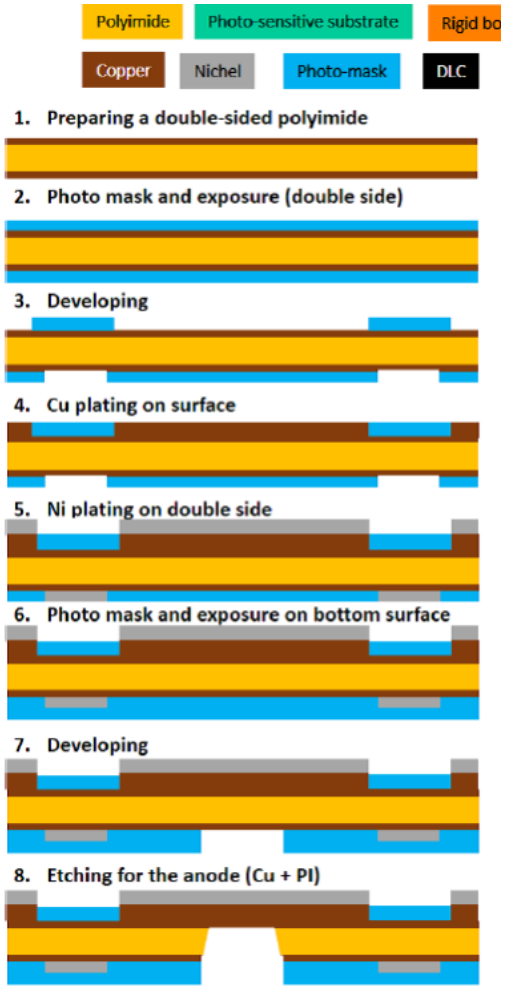


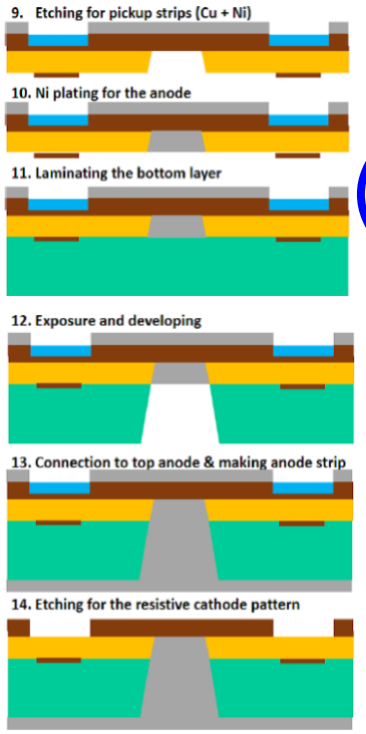
- Use sandblasting to increase the roughness of APICAL, then increase the adhesion of APICAL and DLC;
- Using galvanized Cu to seal the cavities inside the Sputtering Cu;

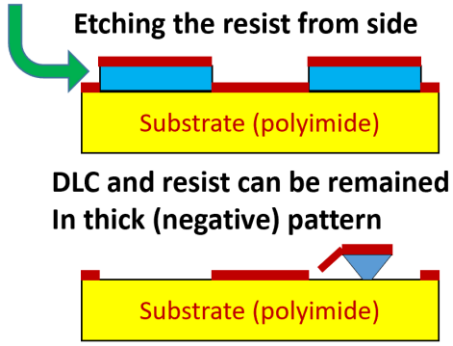
P. Verwilligen, MPGD2019, 07-05-2019

μ-PIC with resistive DLC Cathode

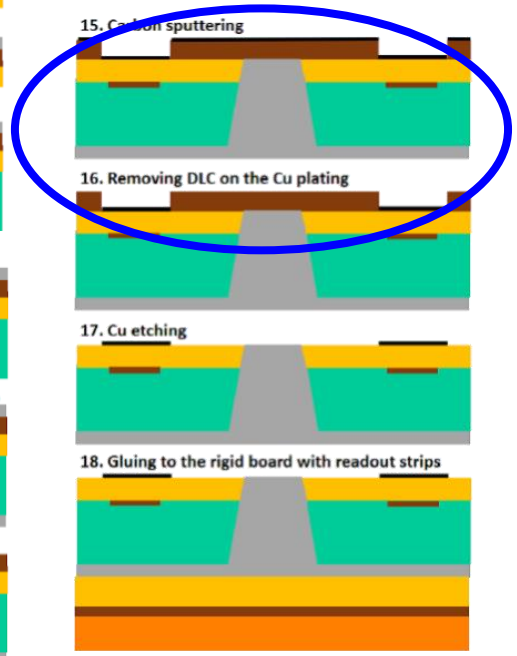




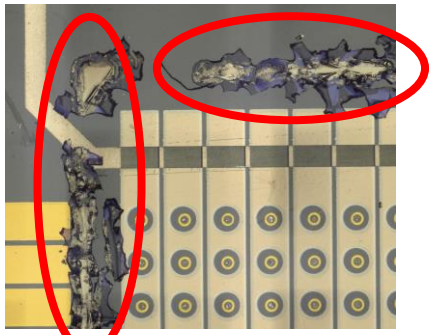




Lift-off using metal

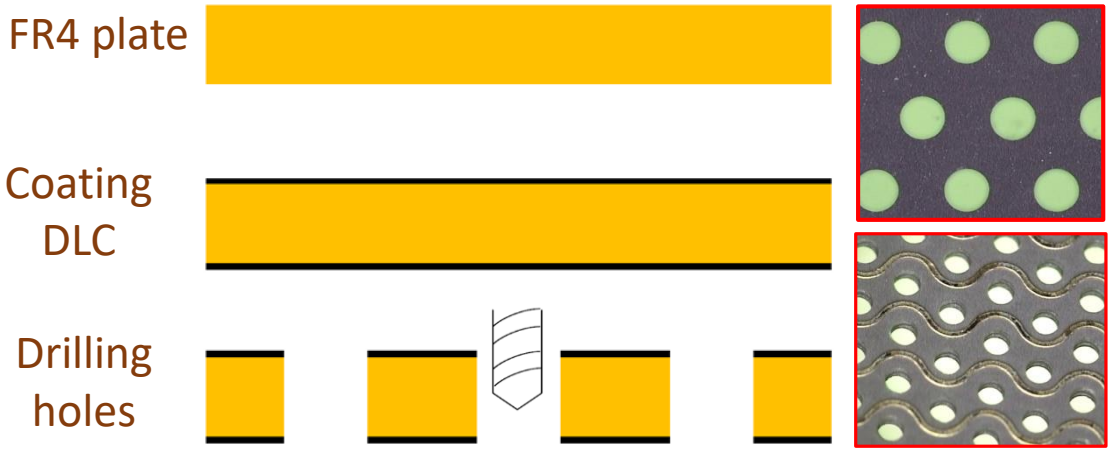


Photoresist with DLC

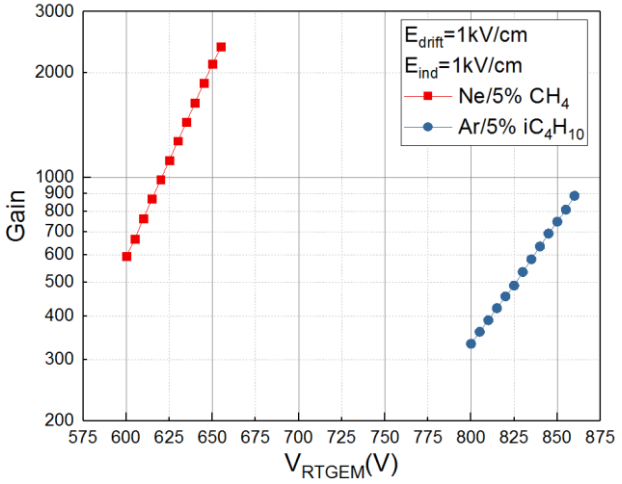


Resistive THGEM

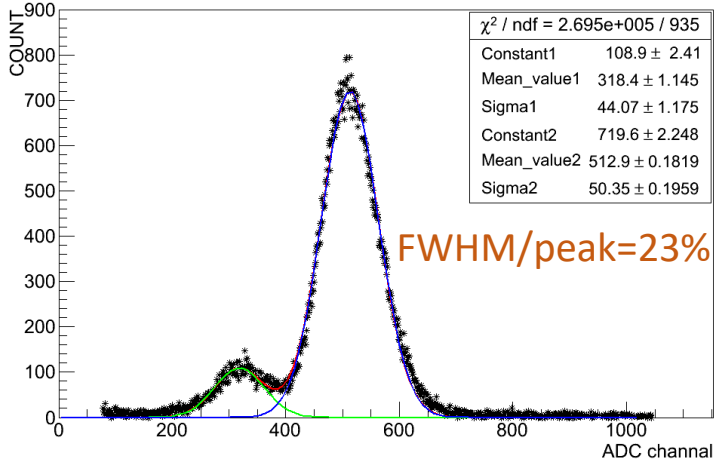
RTGEM production process

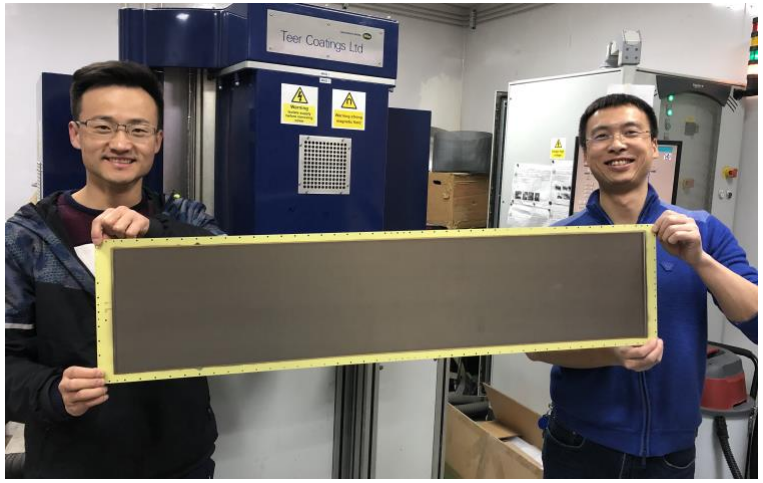


Gain vs. HV

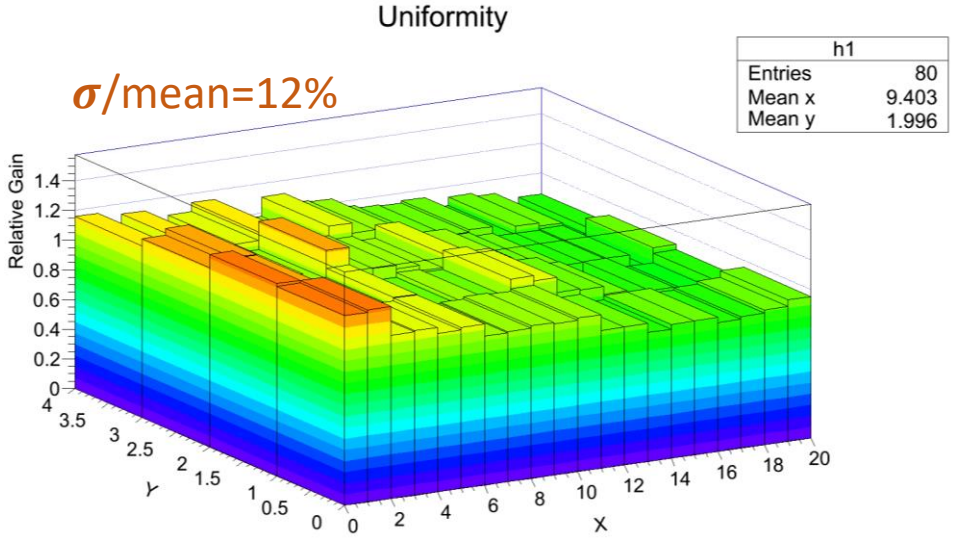


Spectrum of 8keV X-ray



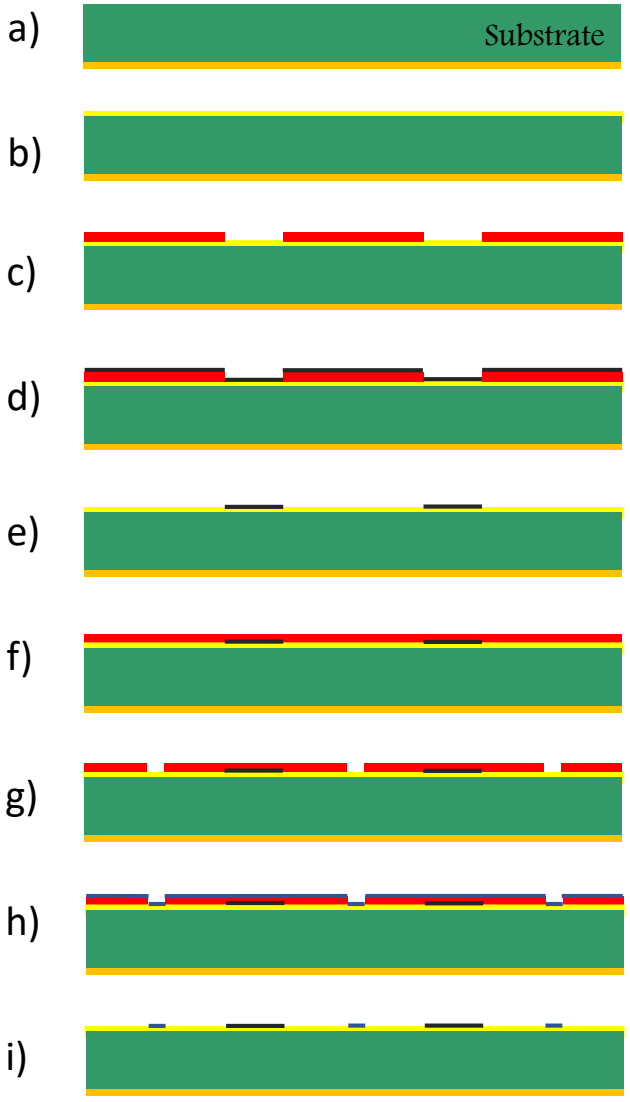


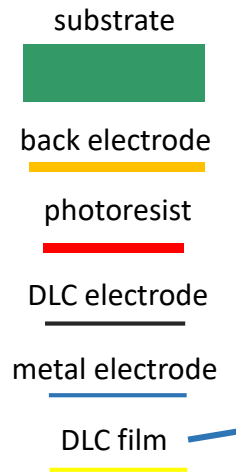
Uniformity

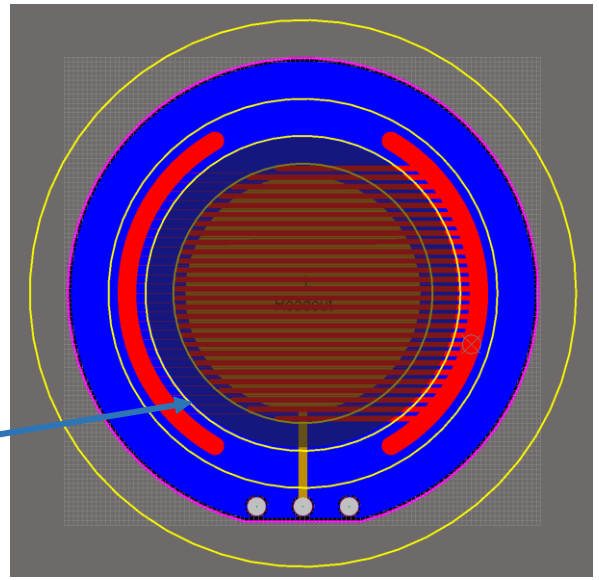


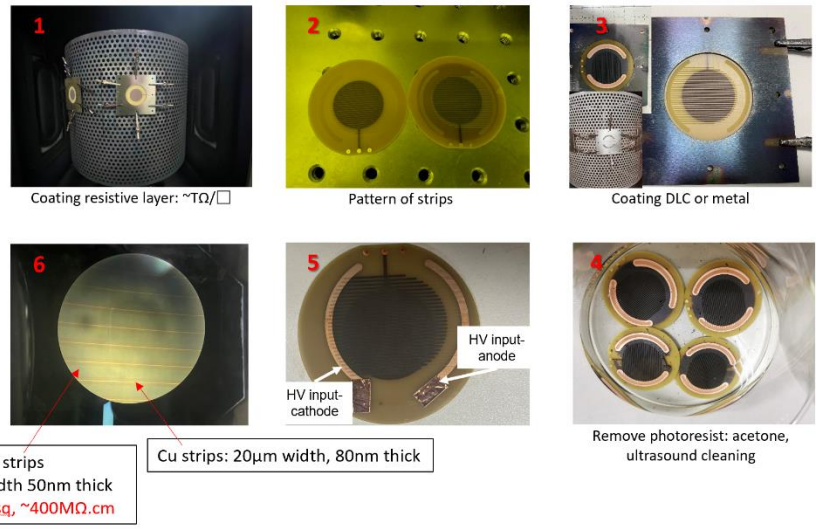
RMSGC Made by Lift-off Method

This project is still ongoing

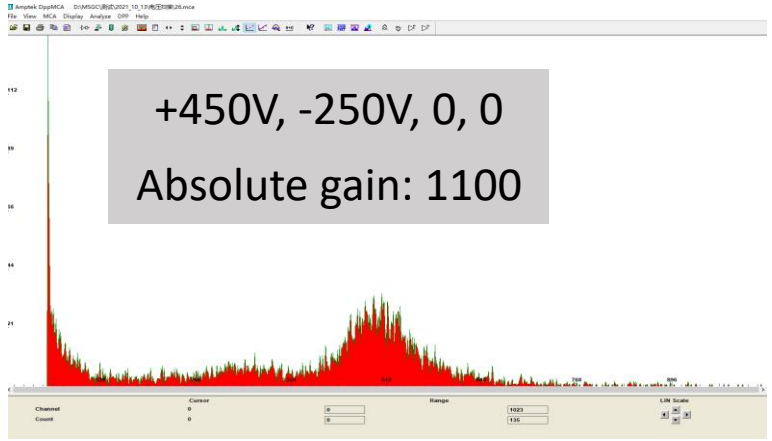


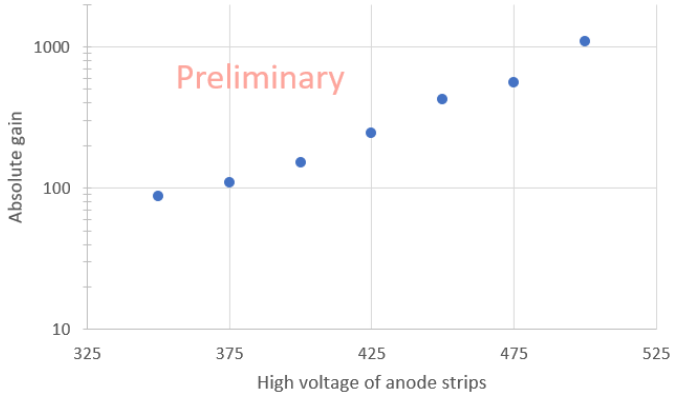






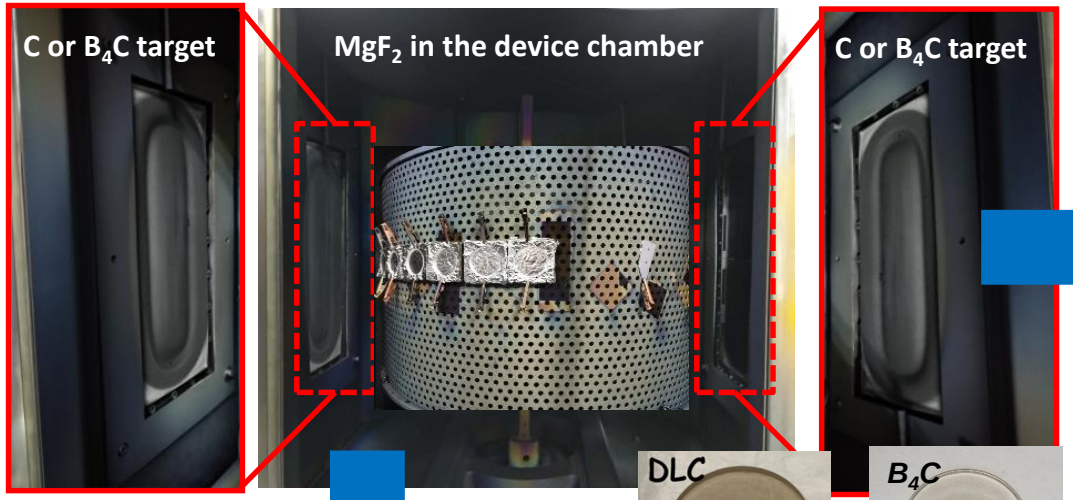
Anode strips: **20μm**
Cathode strips: **600μm**
Pitch: **1mm**

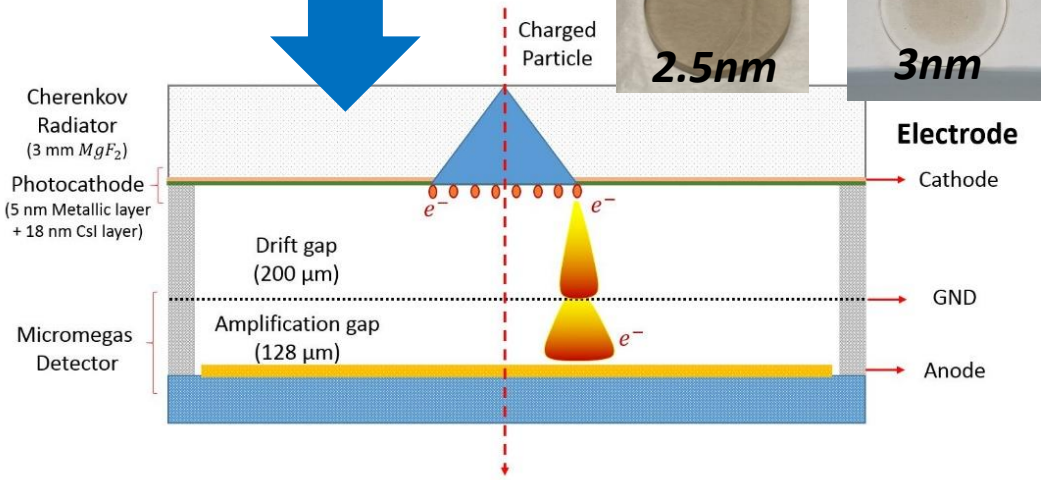




DLC on MgF_2—Robust photocathode for Picosec-MM

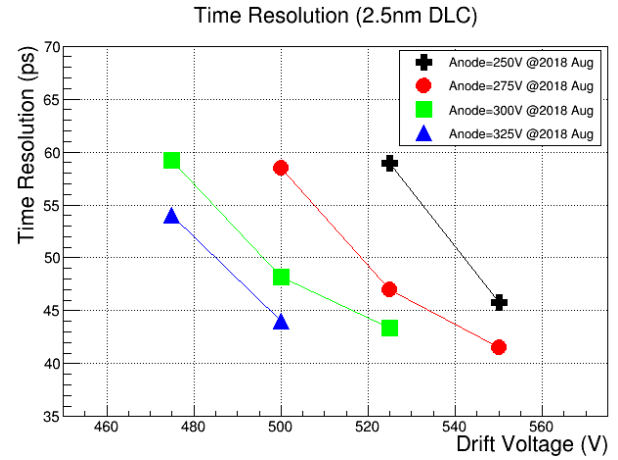
DLC & B_4C/a-C:B photocathode for PICOSEC-MICROMEGAS

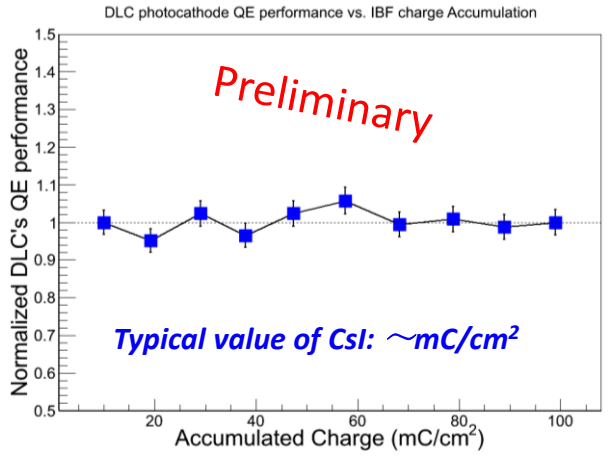


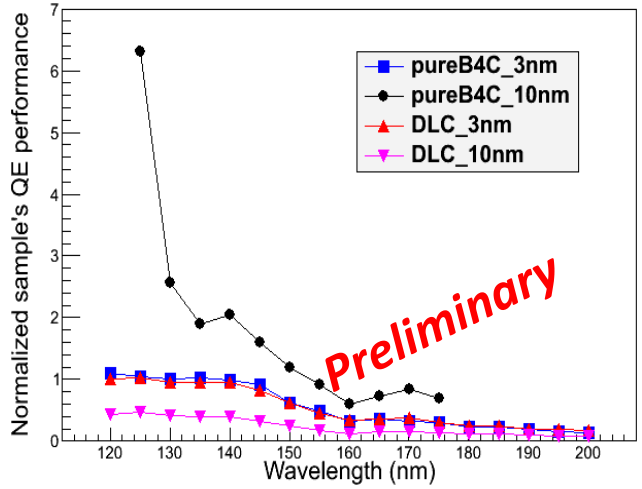


Anode/Drift Voltage (V)	Time resolution (ps)	
	Aug.	Oct.
250/-550	45	37
275/-525	47	38
275/-550	42	34
300/-500	48	39
300/-525	43	34

Preliminary

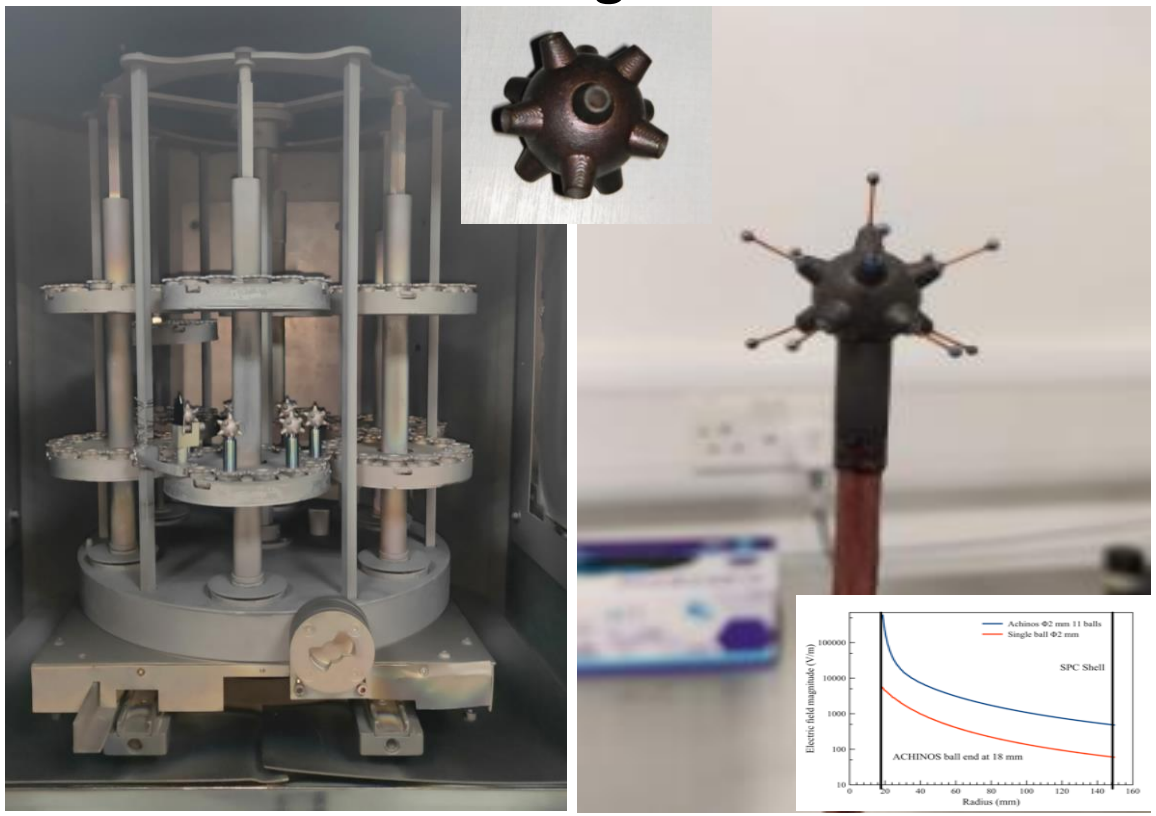






DLC on spherical resin—Resistive ACHINO

3-axis DLC coating for ACHINO



The electric field is stronger (7x) with multi ball compared to a single read-out

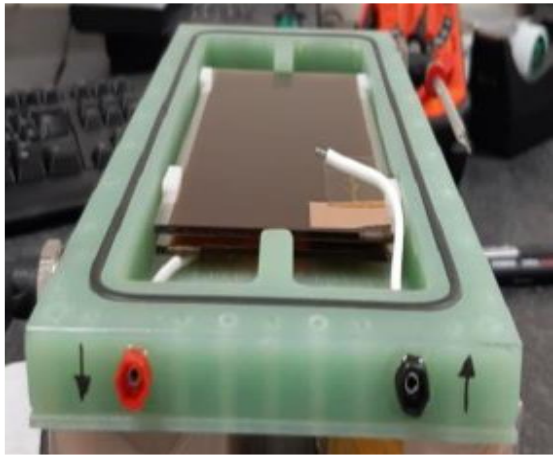
I. Giomataris, RD51 Collaboration Meeting, 22-10-2019

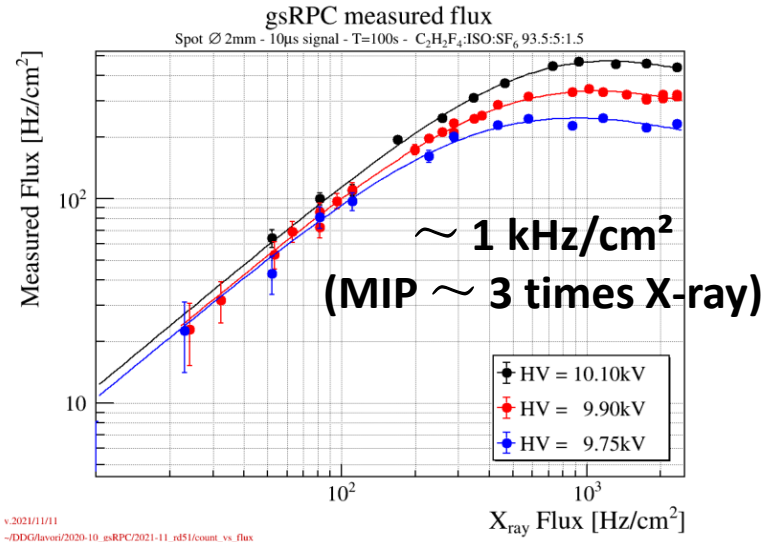
DLC coating for Degrader

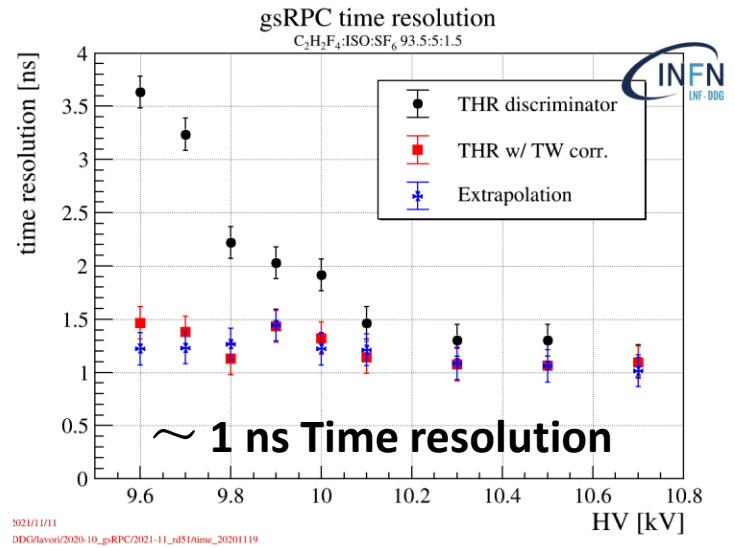
More details can be found in presentation of K. Nikolopoulos on this conference

The Surface Resistive Plate Counter (sRPC)

- **Surface resistivity electrodes** manufactured with industrial sputtering techniques of **DLC on flexible supports**
- The technology allows to realize electrodes with a surface resistivity in a **very wide range, 0.01～ 10GΩ/□**
- **High density current evacuation schemes**, similar to the ones used for **resistive MPGD** (µRWELL), can be implemented **to increase the rate capability** of the detector







1. Introduction of the DLC

2. Applications of resistive DLC in gaseous detectors

3. Summary

Summary

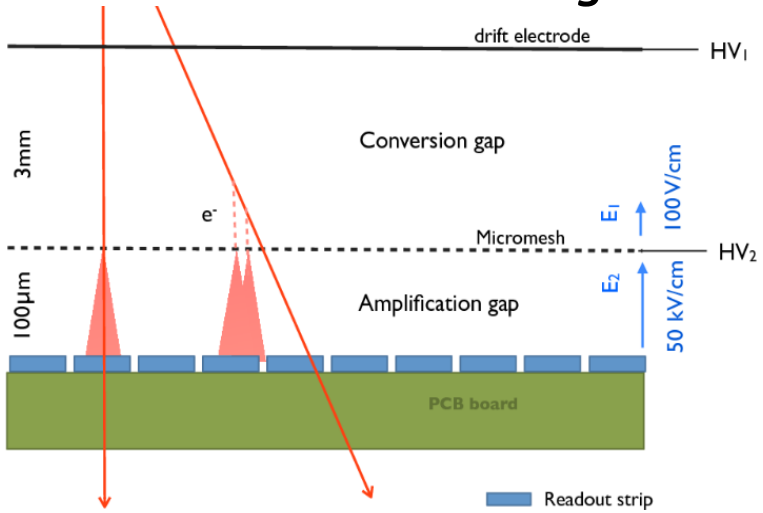
- DLC has been already introduced in the manufacturing of innovative MPGDs as resistive electrode, in spite of the possibility to sputter DLC on large area with good chemical/physical tolerances, there are still some open problems requiring for a dedicated detailed studies.

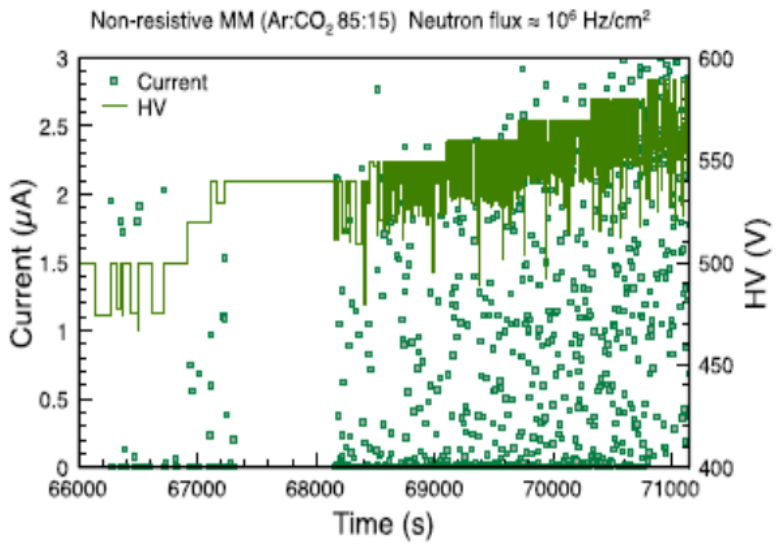
- DLC with Copper (DLC + Cu) is an advance material for MPGD manufacture, it is able to open new possibilities to produce advanced MPGD architectures.

Backup

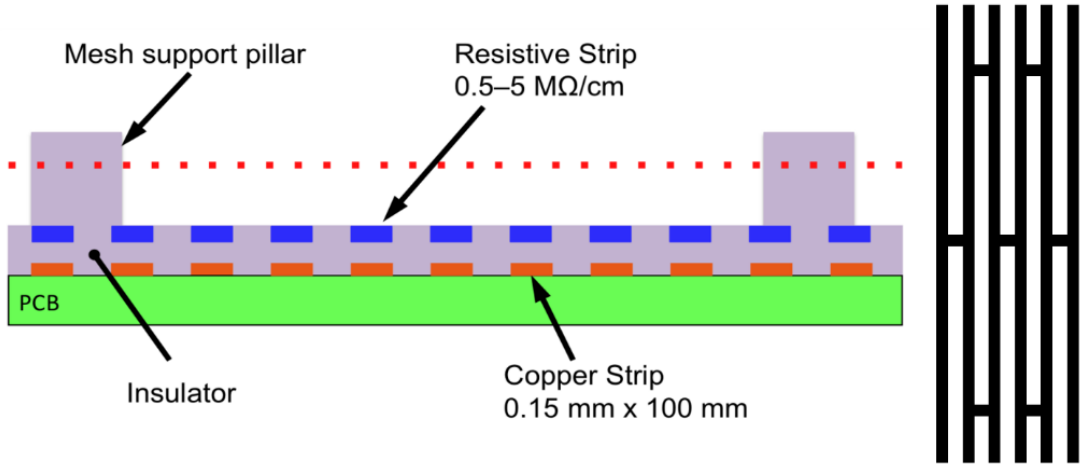
Resistive Electrode Can Effectively Suppress The Discharges

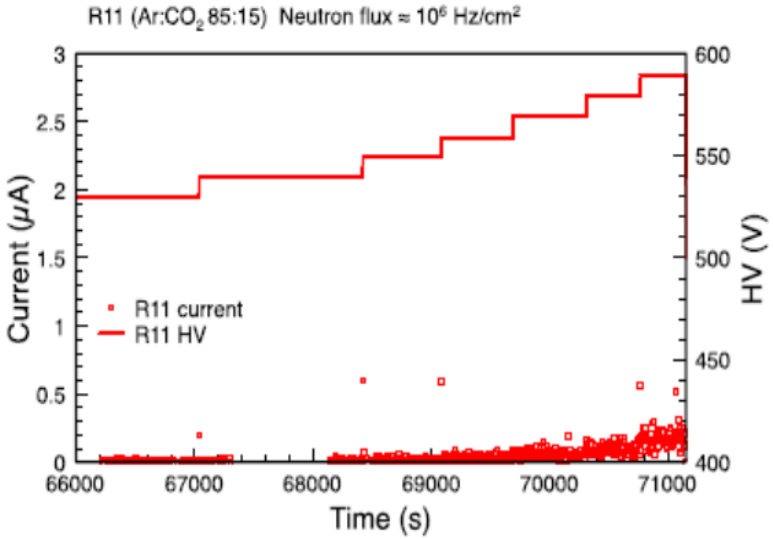
Non-Resistive Micromegas





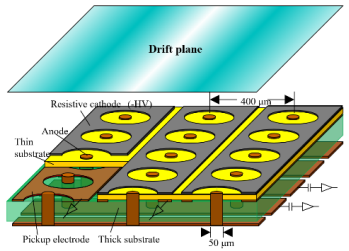
Resistive Micromegas

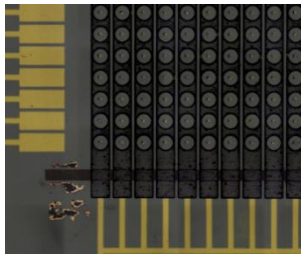


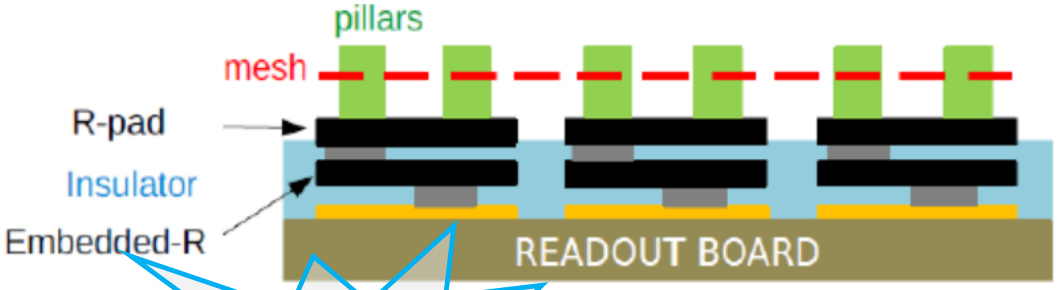


Resistive Materials Based on Carbon Loaded Pastes

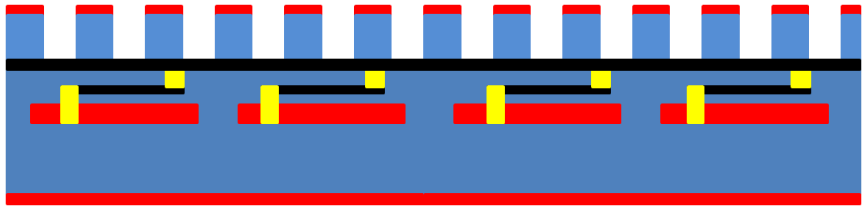
Resistive materials based on Carbon loaded pastes have already widely used in MPGDs to suppress the discharges and reduce the damaging effects on MPGDs

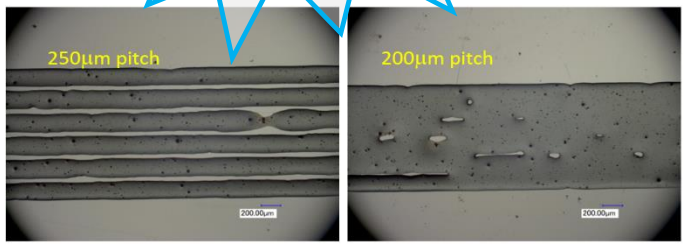


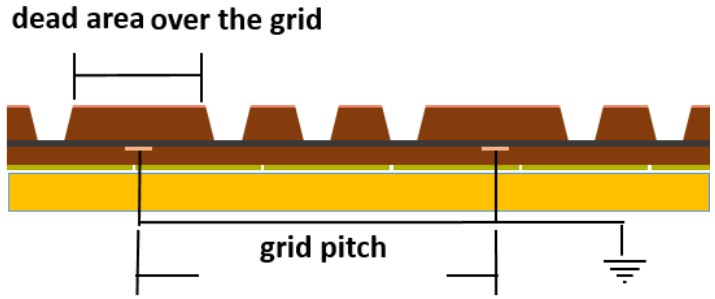




However







- × *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

RD51 Common Project & Resistive DLC Collaboration

DLC based electrodes for future resistive MPGDs

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

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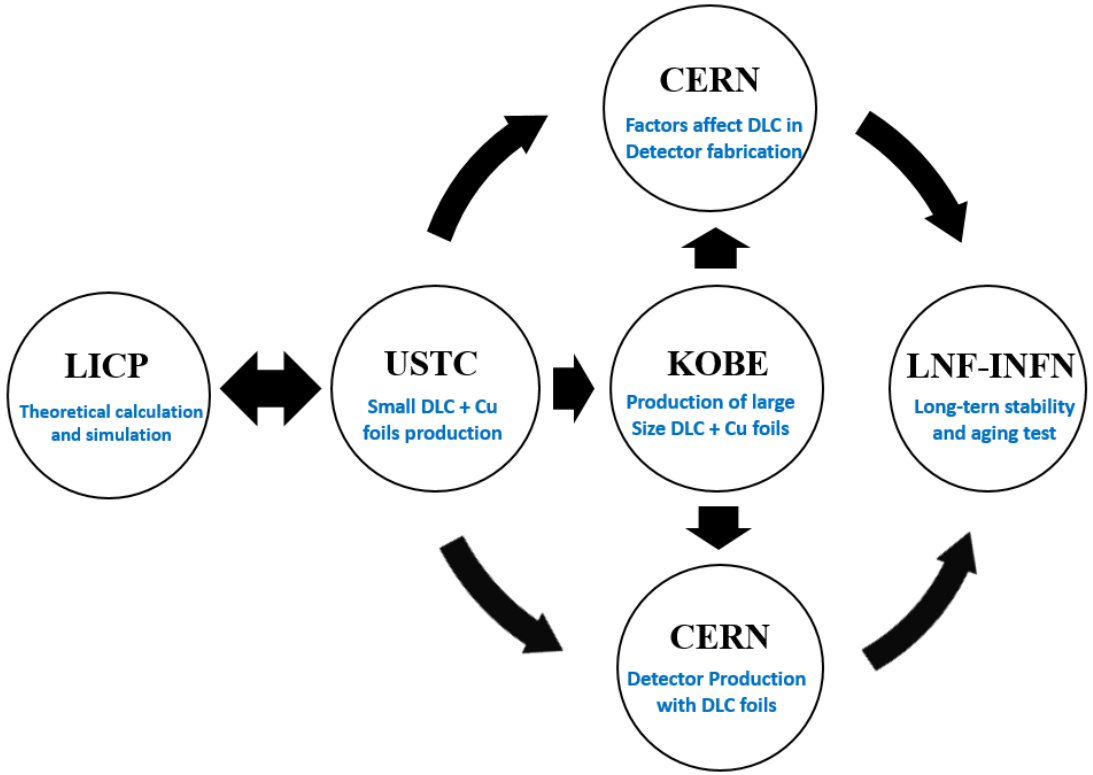
telephone number: +86-551-63607940
e-mail: zhouyi@mail.ustc.edu.cn

RD51 Institutes:

1. *State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, contact person: Yi Zhou e-mail: zhouyi@mail.ustc.edu.cn*
2. *Kobe University, contact person: Atsuhiko Ochi e-mail: ochi@kobe-u.ac.jp*
3. *CERN contact person: Rui de Oliveira e-mail: Rui.de.Oliveira@cern.ch*
4. *Laboratori Nazionali di Frascati dell'INFN contact person: Giovanni Bencivenni e-mail: Giovanni.Bencivenni@lnf.infn.it*

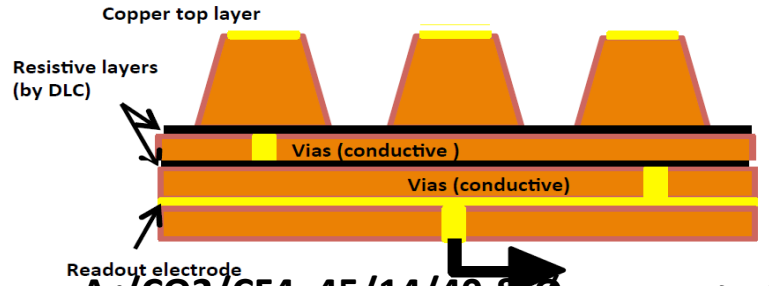
Ext. Collaborators: 1. *State Key Laboratory of Solid Lubrication, Lanzhou Institute of Chemical Physics, Chinese Academy of Science contact person: Lunlin Shang e-mail: shangll@licp.cas.cn*



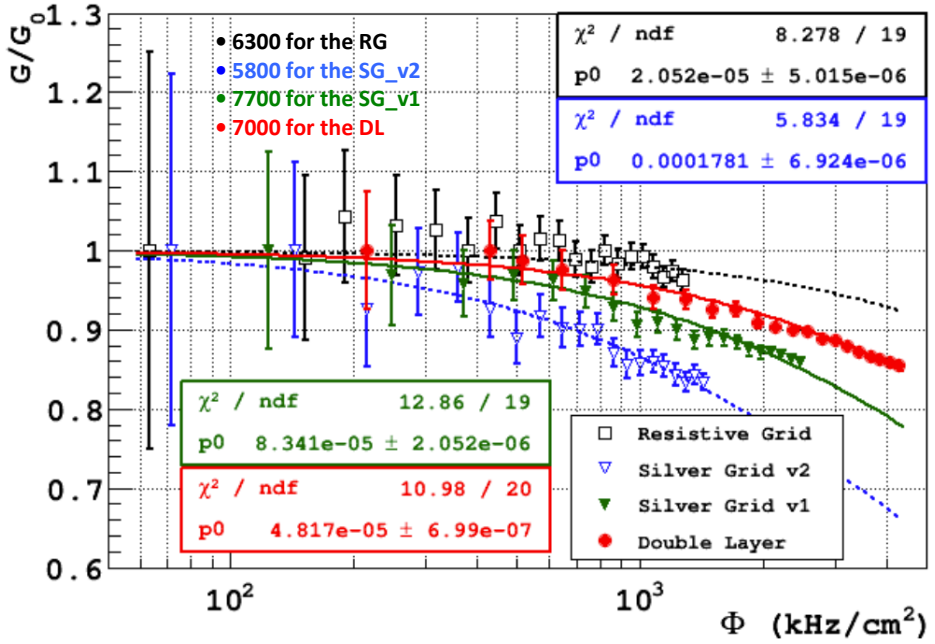
Goal of this project:

1. **Define a stable and well controlled DLC and DLC+Cu processing method for the production of MPGD electrodes**
2. **Studying the long-term stability under irradiation of DLC and DLC-based detectors.**

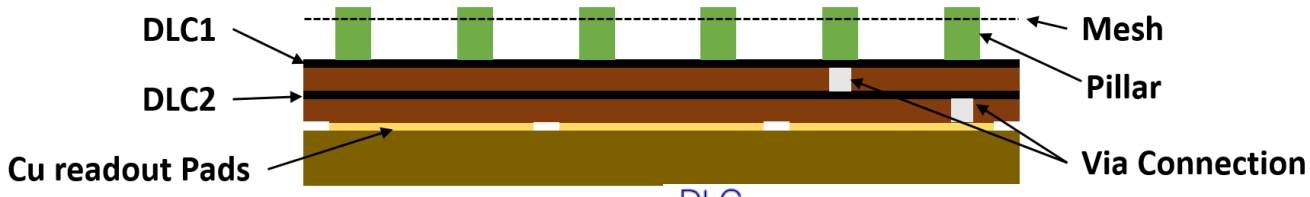
µRWELL & Micromegas with Resistive DLC



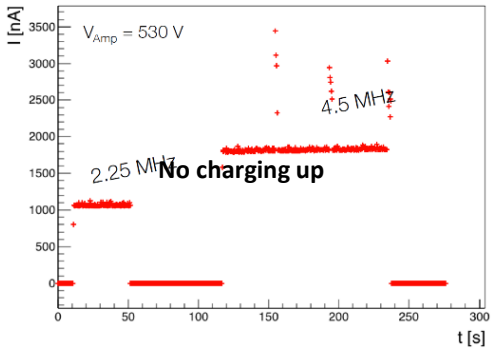
Ar/CO2/CF4=45/14/40 & $\emptyset_{\text{X-RAY SPOT}} \sim$ 4 cm

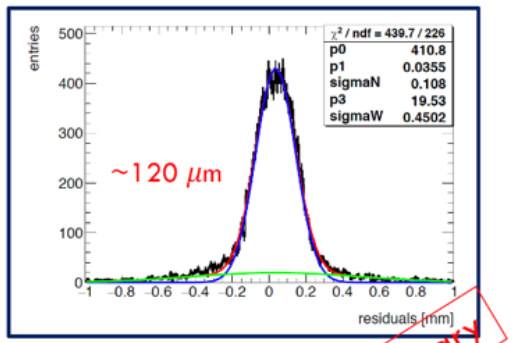


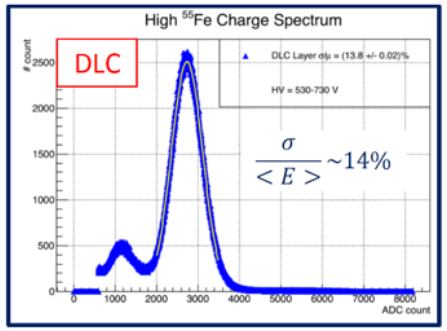
✓ *High rate capability (>1MHz/cm²)*

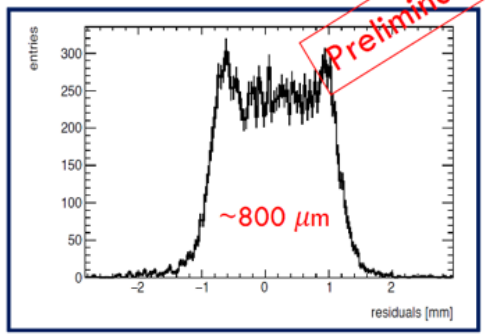


DLC









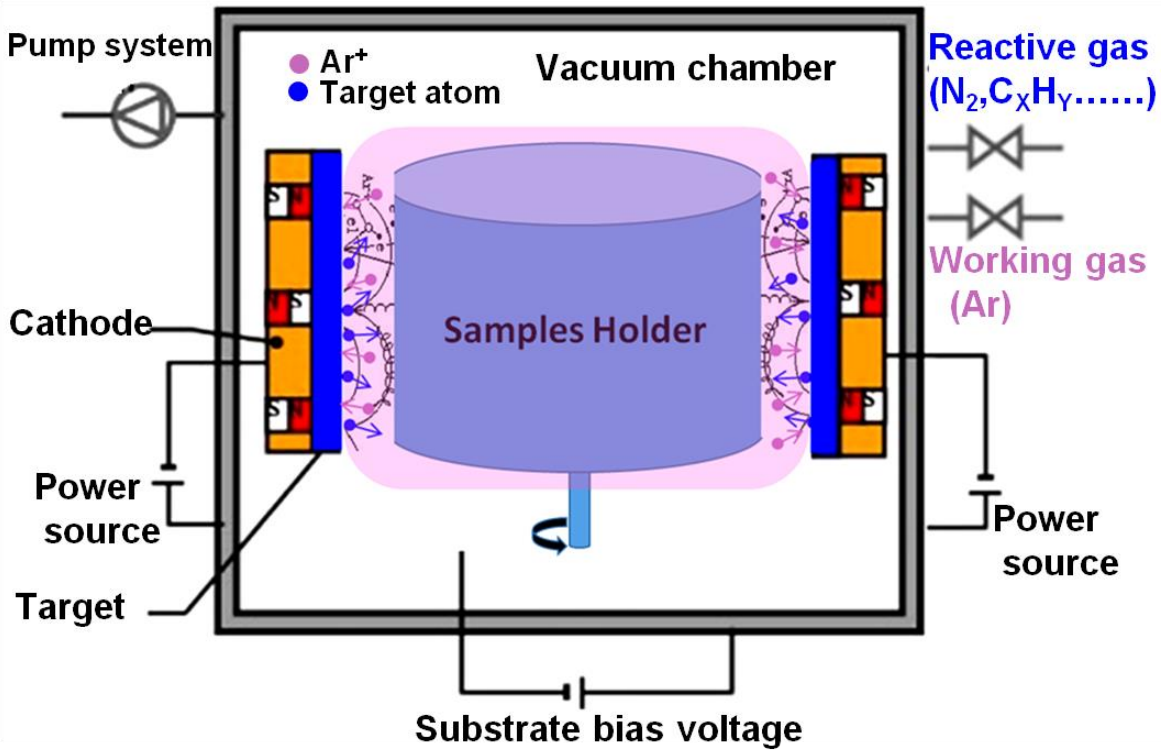
✓ *Very good position resolution and energy resolution*

✓ *No charging up effects anymore*

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

M.Iodice, ICHEP 2018, Seoul,7-July-2018

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

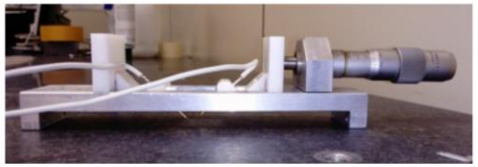
The DOCA measurement

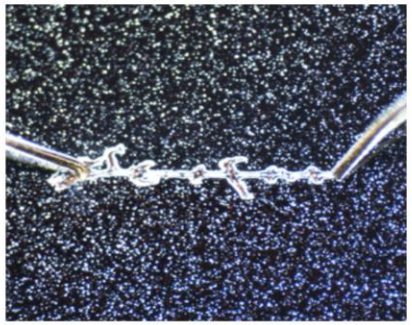
Data on this page comes from Resistive DLC Collaboration

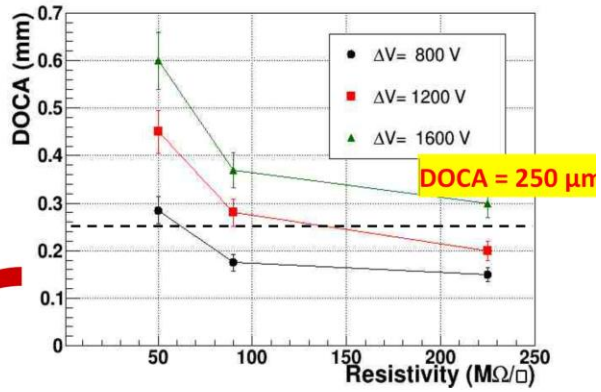
➢ **For better understand of the safety distance**

Conductive Grid: optimization

In order to reduce the dead area, we studied the Distance Of Closest Approach *(DOCA) without discharges* between two tips connected to an HV power supply. We recorded the minimum distance before a discharge on the DLC occurred *vs* the ΔV supplied for foils with different surface resistivity





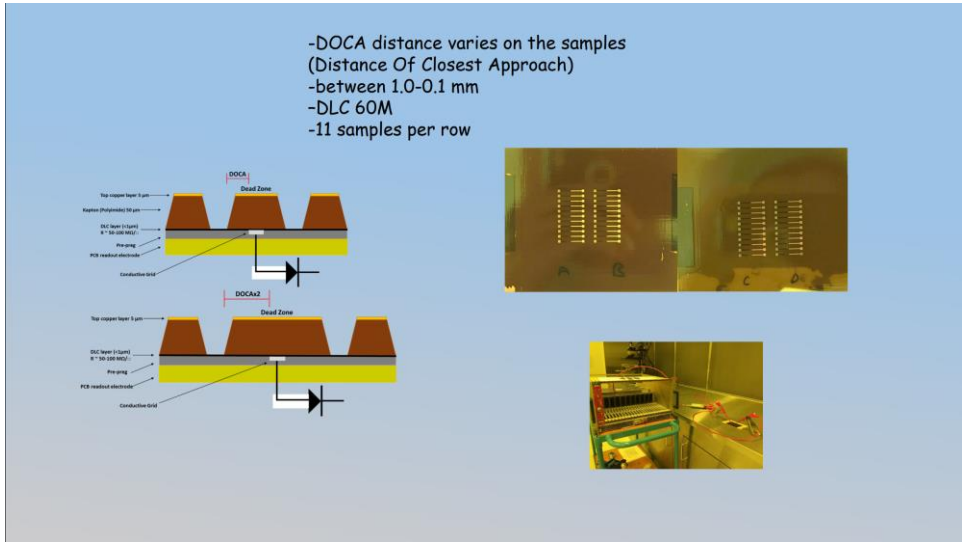


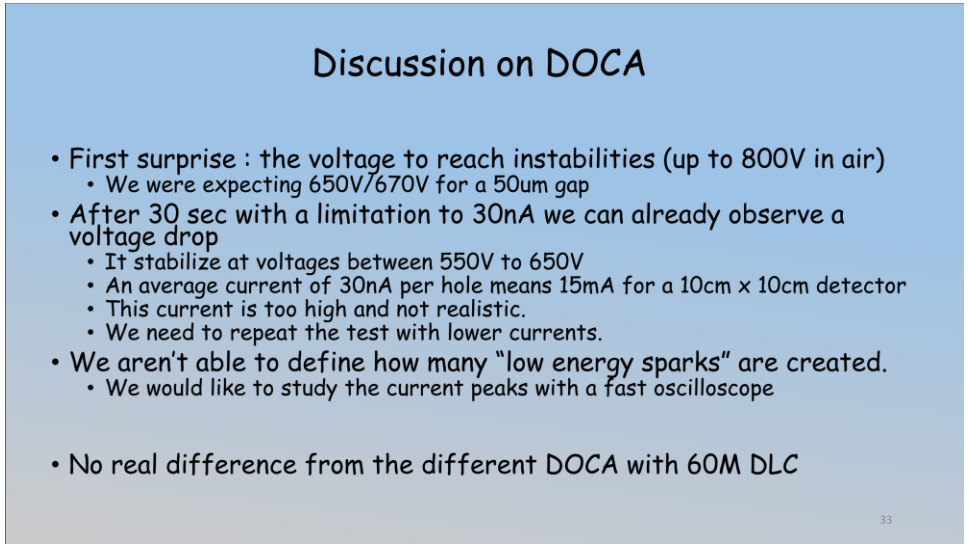
ρ > 60 MΩ/□ → DOCA < 250 µm

Conclusions:

➢ **250µm is safe enough for resistivity larger than 60MΩ/□;**

➢ **More systematically measurements should be done in future;**





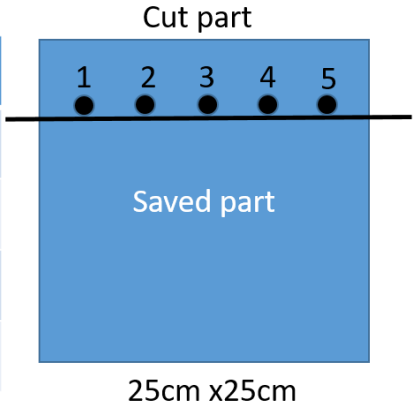
Increasing the Adhesion by “One-Batch” Method

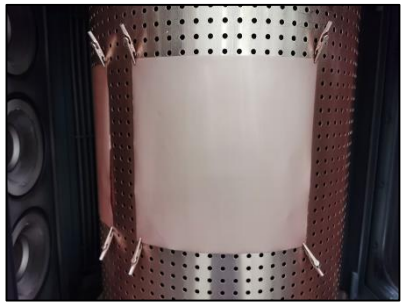
Flow chart of the DLC + Cu by “One-batch” method

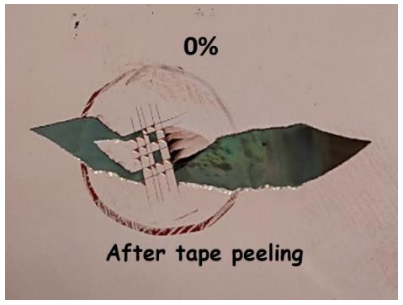
APICAL Clamping → Vacuum Pumping → DLC Deposition → C & Cr Co-deposition → Cr Deposition → Cr & Cu Co-Deposition → Cu Deposition → Cooling taking down

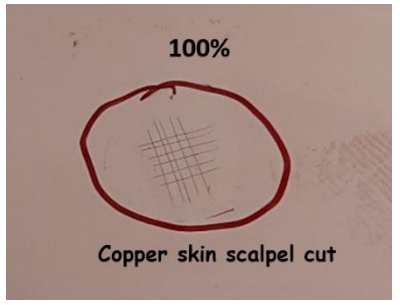
Adhesion Test

Batch No.	Adhesion1	Adhesion 2	Adhesion 3	Adhesion 4	Adhesion 5
H2020-06-28-3	100	100	100	100	100
H2020-06-28-3	100	100	100	100	100
H2020-06-28-4	100	100	100	100	100
H2020-06-28-4	100	30	30	60	60





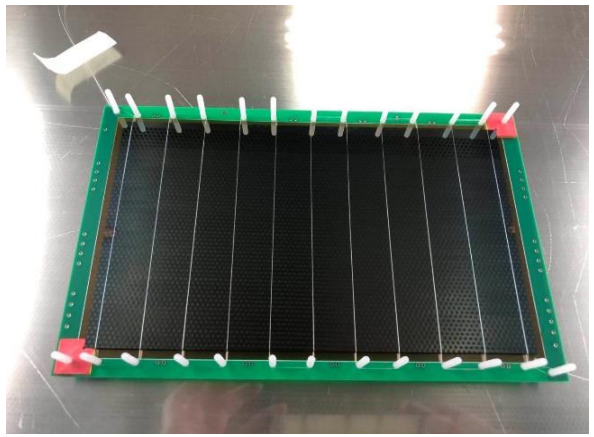


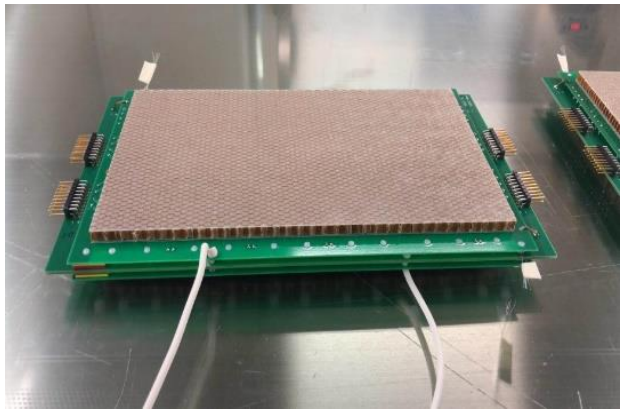


- “One-Batch” method shows very good adhesion, almost the same as the Cr/APICAL of the raw material;
- The 4th sample is not perfect, the possible reason is the surface is not clean and the PSE process is missing;
- This method is “blind” to the DLC resistivity, maybe it is (only?) suitable to the very low resistivity application;

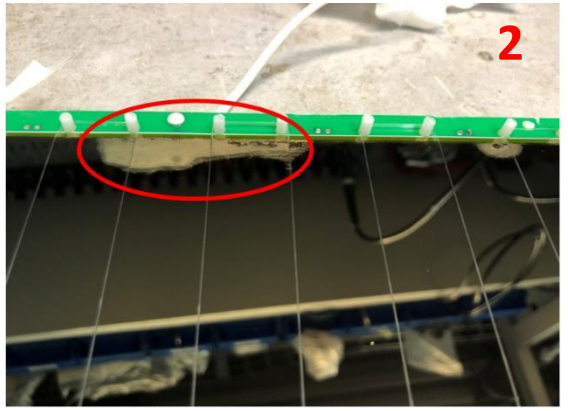
DLC on glass—High rate MRPC

Using DLC to speed up the charge neutralization in MPRC





Problems found in current DLC-MRPC



Challenges:

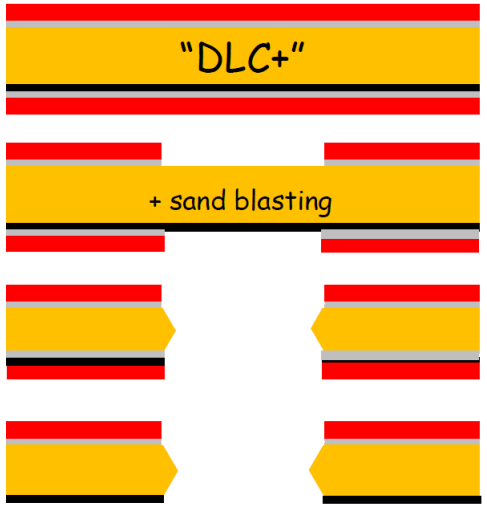
1. Large DLC inner stress compared to the other substrate;
2. Worse adhesion;
3. Difficult to coat on the side edge due to super large roughness
4. Can be removed by alcohol when use high temperature deposition

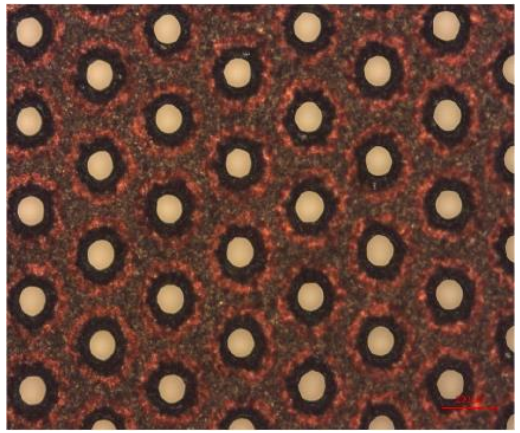
Possible solutions:

- Try to make the edge more smooth;
- Try to add some interlayer based on Silicon/Silicon compound;

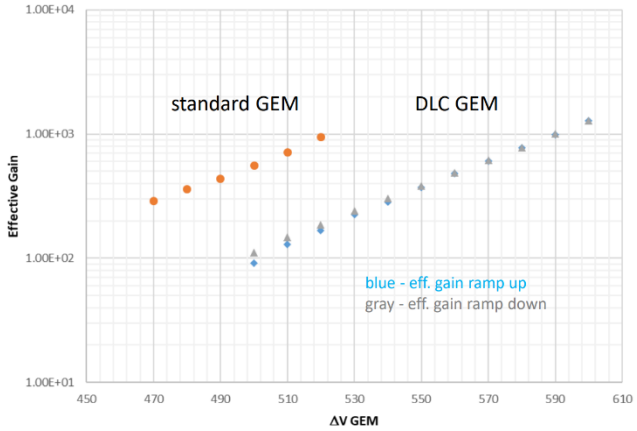
More details can be found in:
https://agenda.infn.it/event/19942/contributions/108461/

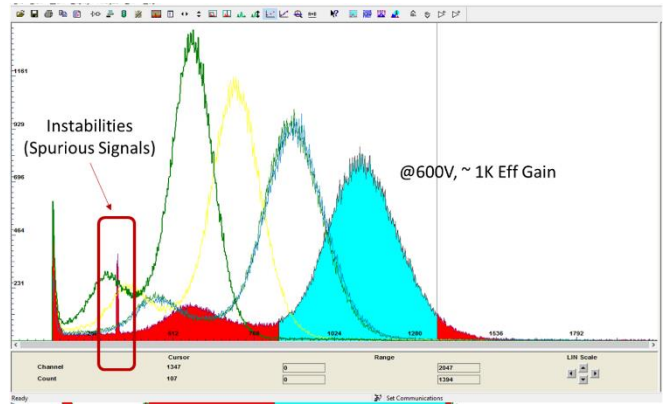
Resistive GEM





GEM with Resistive DLC Electrode on Bottom side



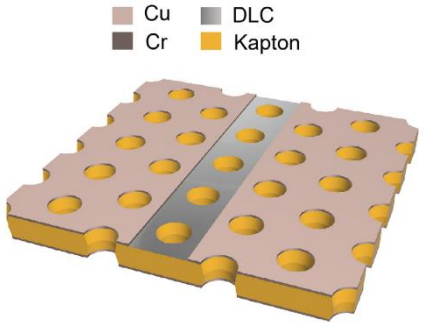


Problem:

Sandblasting may cause the delamination

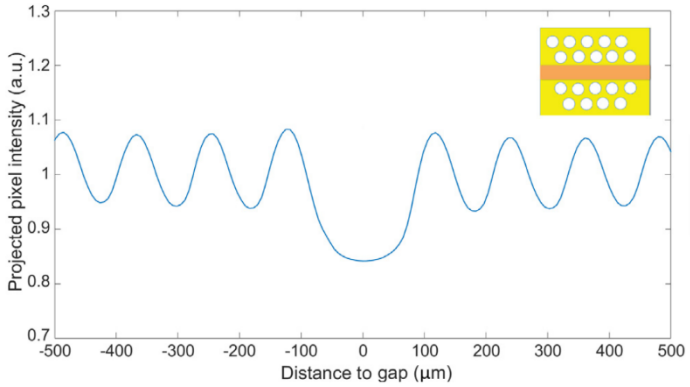
Possible Solution:

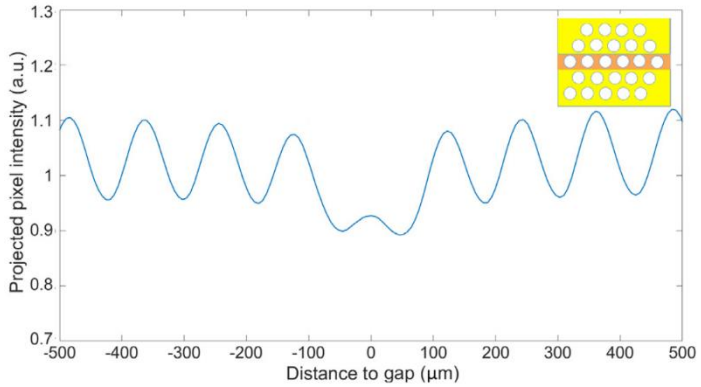
Keep the photoresist on Cu during the Sandblasting process



R. De Oliveira, INSTR2020, 28-02-2020

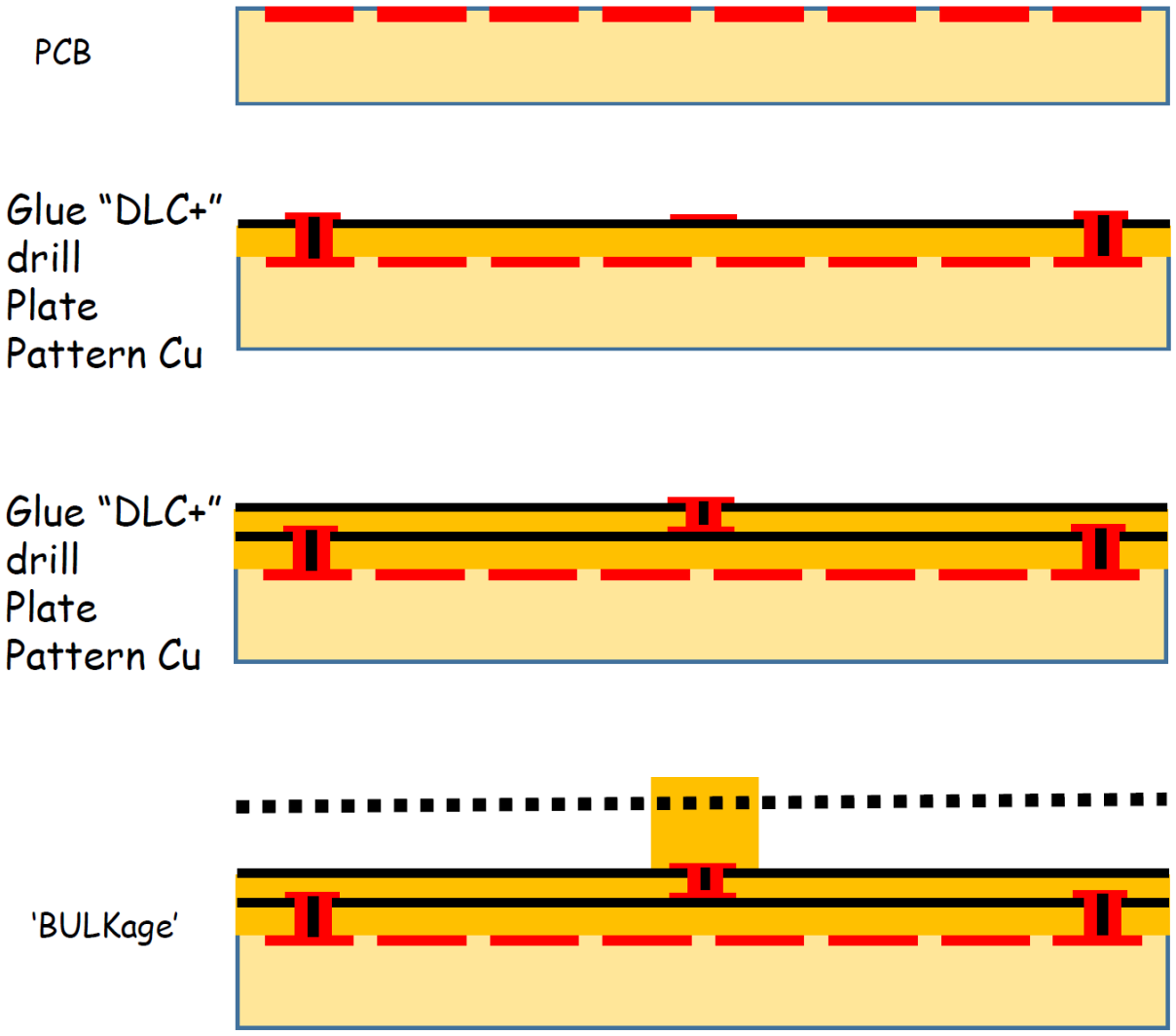
GEM with Holes between the Sectors

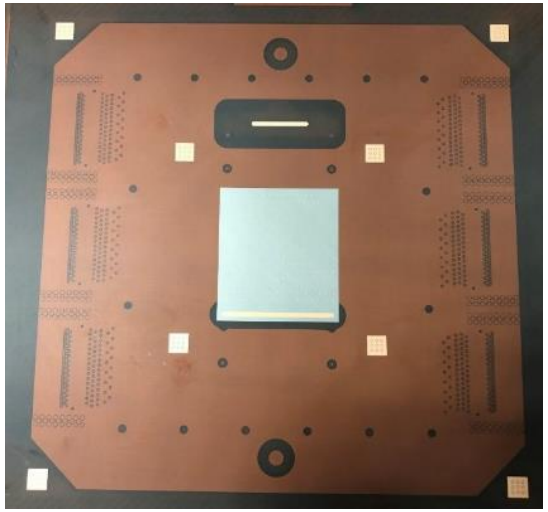


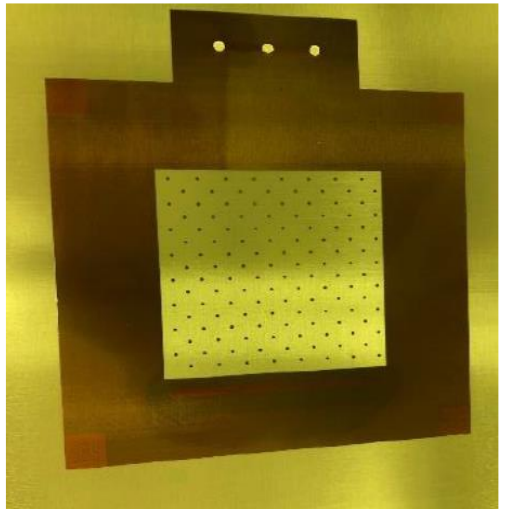


M. Lisowska, *RD51 Collaboration Meeting, 23-10-2019*
A.P.Marques, et al, *NIMA 961 (2020) 163673*

Micromegas Made by Sequential Build-Up (SBU) Technique

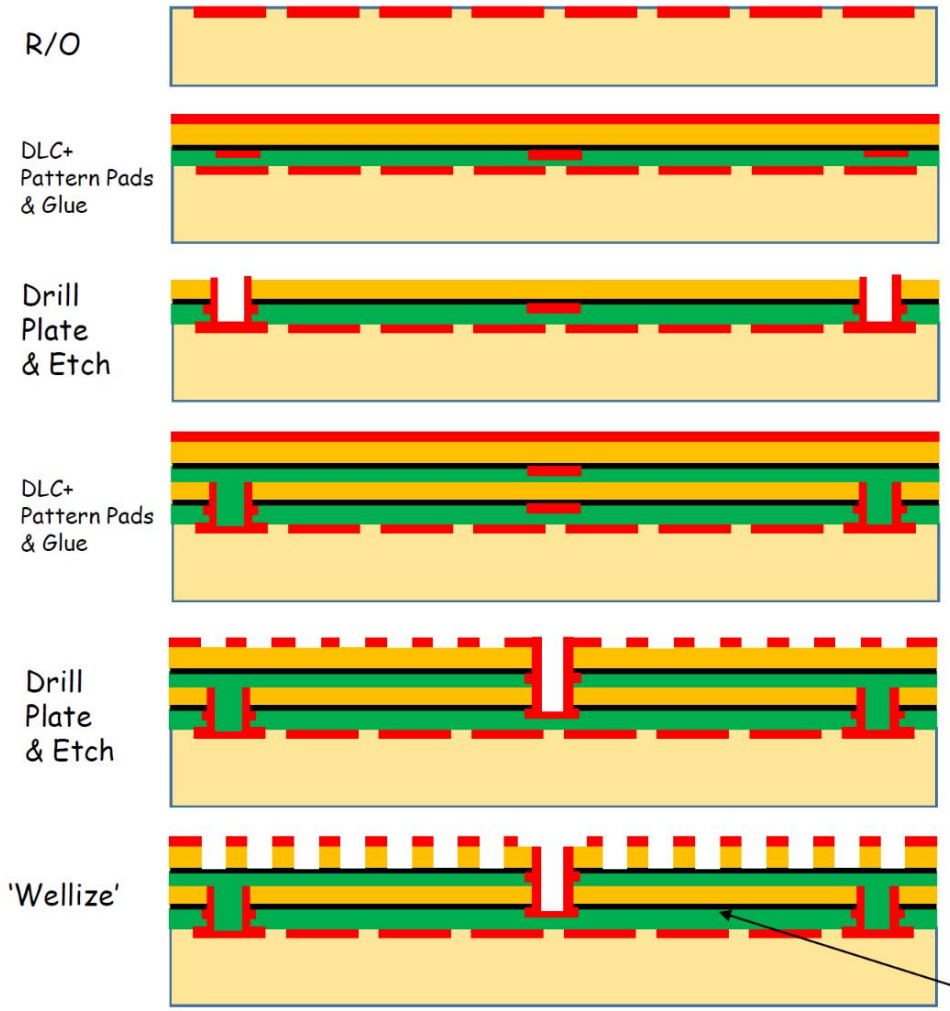






- Extra Large DOCA(3mm)
- Adjustable evacuation density VS rate
- No problem with layers registration
- Good energy resolution
- 100% compatible with STD PCB processes
- Needs "DLC + Cu"

µRWELL Made by Sequential Build-Up (SBU) Technique

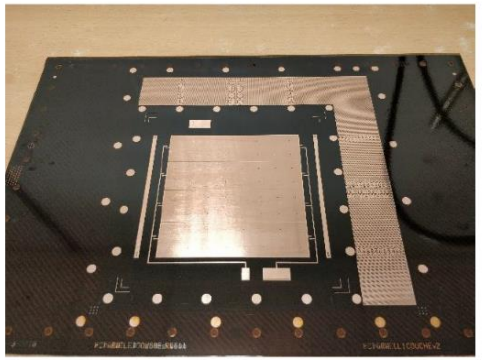


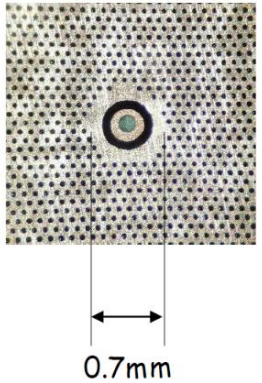
SBU type

Sequential Build Up

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

-Needs DLC+ base material

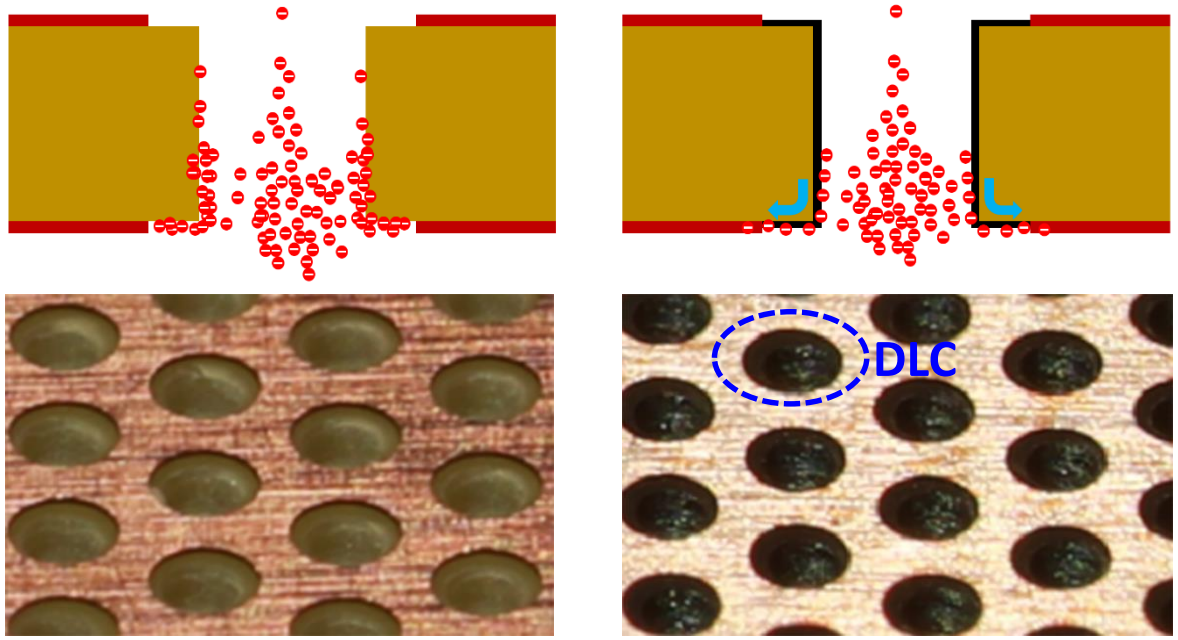


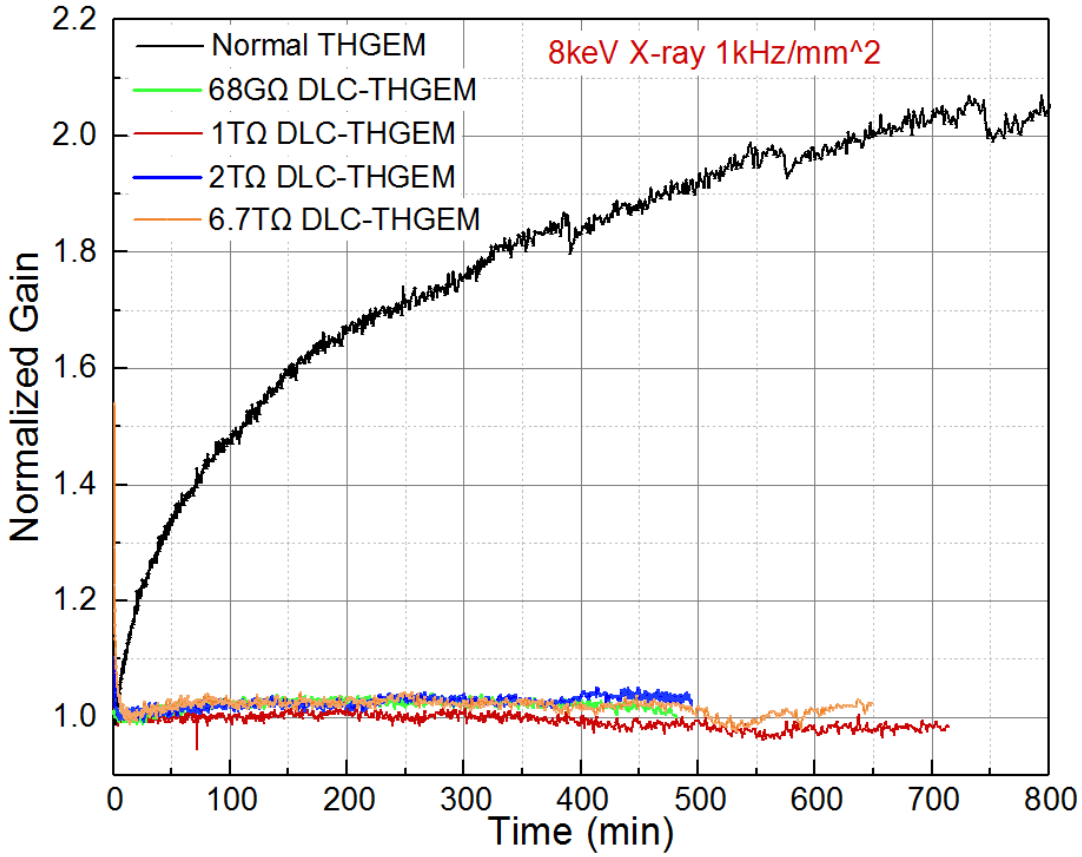


Problem:

When the detector goes to large area, the deformation of the APICAL foil will be significant and cause alignment problems when drilling holes

Remove Charging-up of THGEM by High Resistivity DLC



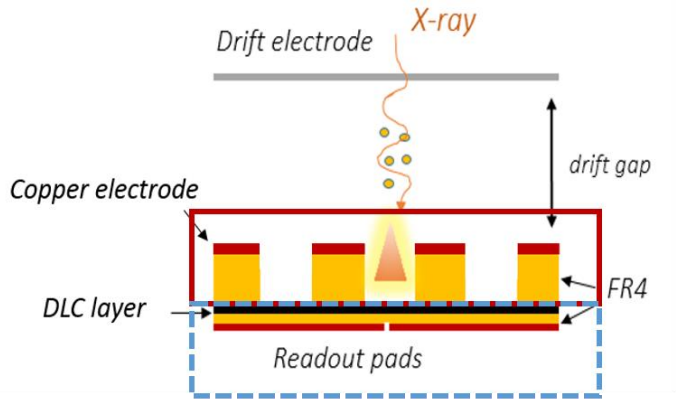


Coating a-C:H DLC on the rim and hole area

Doping hydrogen by adding isobutane from 7sccm to 9sccm

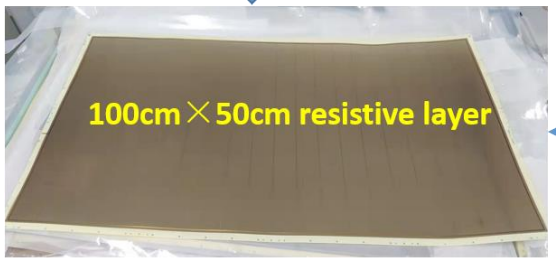
- ✓ ***Easily applied on the current THGEMs;***
- ✓ ***Charging up effect almost removed;***

RWELL Detector Using Separating Readout PCB

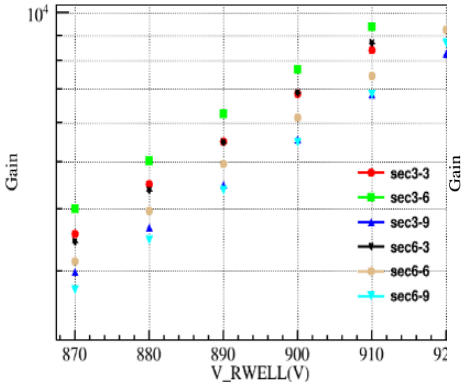


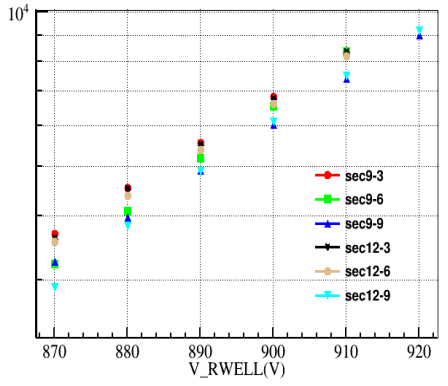
Design methods:

- Divide RWELL foil into 20 sectors
- Separate resistive layer from readout PCB
- Grounding circuit was designed on the resistive layer
- Large readout PCB was composed of 8 pieces

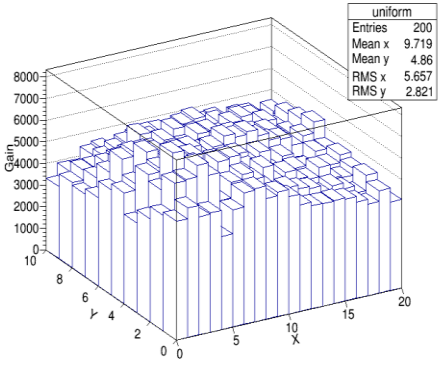


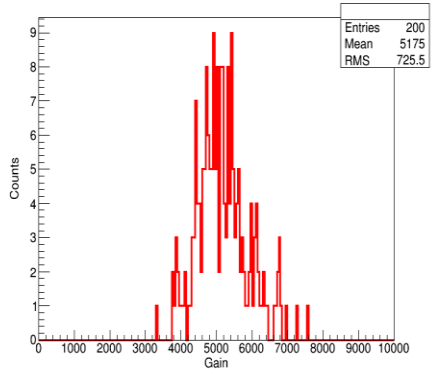
Gluing



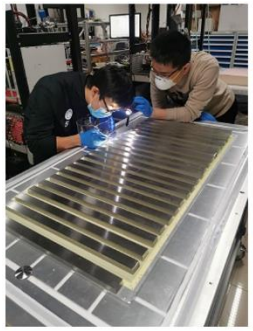


Maximum Gain :～8000

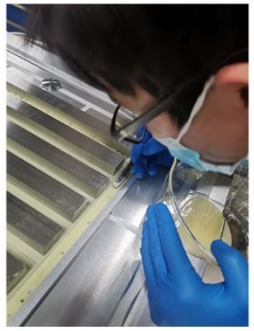


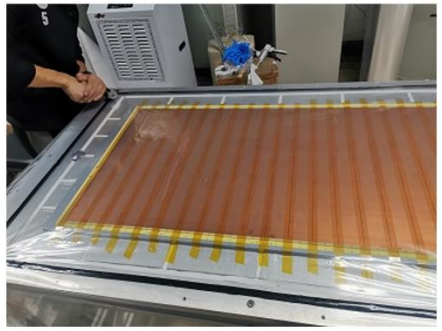


Gain uniformity :～14.0%@ G_0= 5175

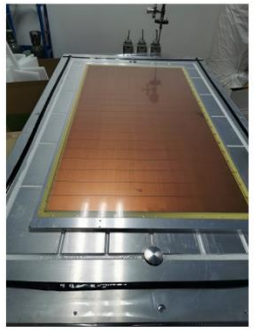


Painting the glue

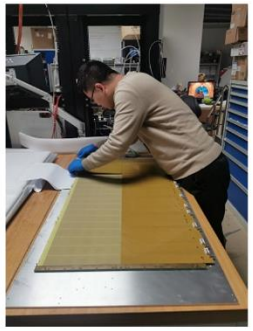




Seal the platform



Pumping and drying



Assembling