DLC Community Contributions from RD51 Common Project

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On behalf of the Resistive DLC Collaboration

RD51 Mini-Week, 12-02-2020

RD51 Common Project

DLC based electrodes for future resistive MPGDs

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

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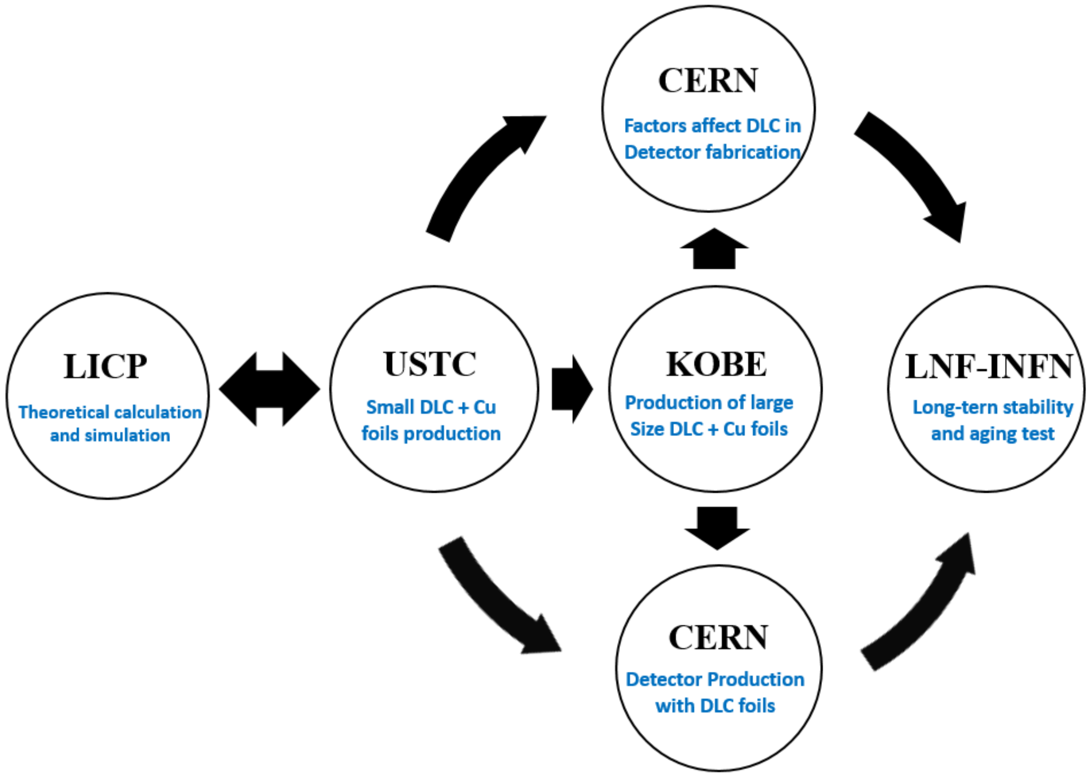
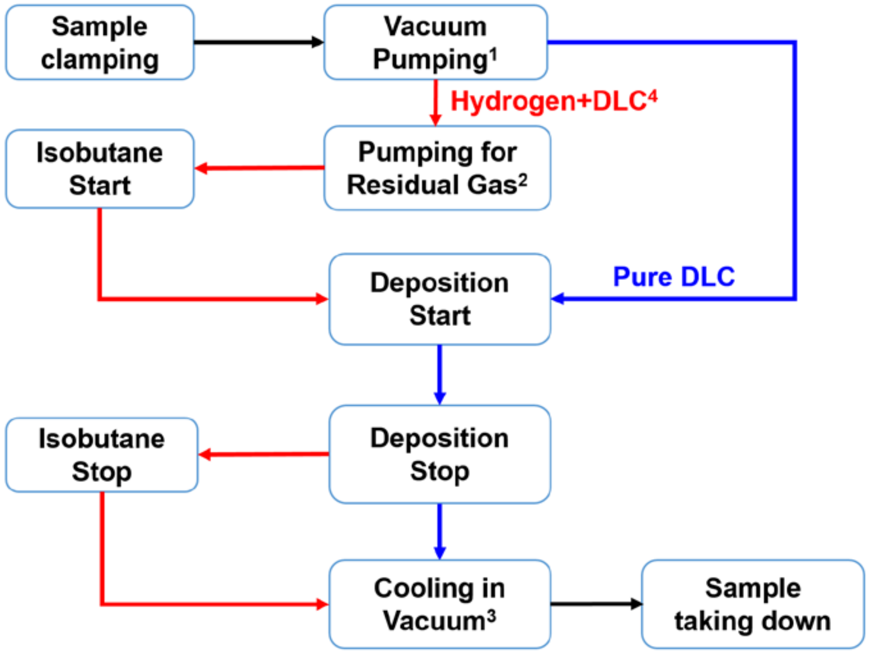
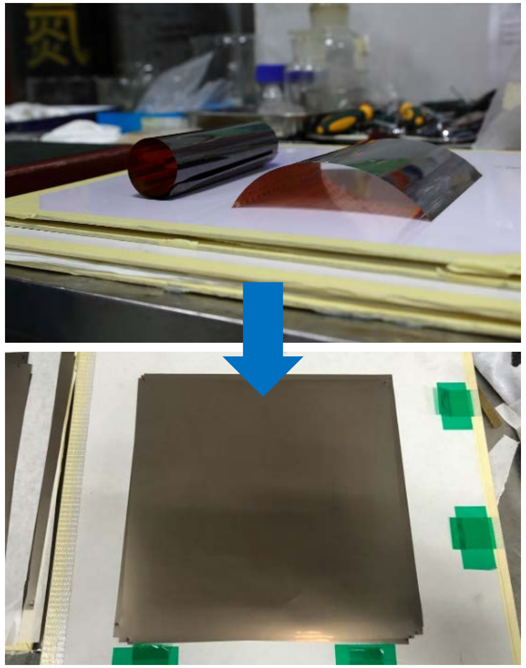


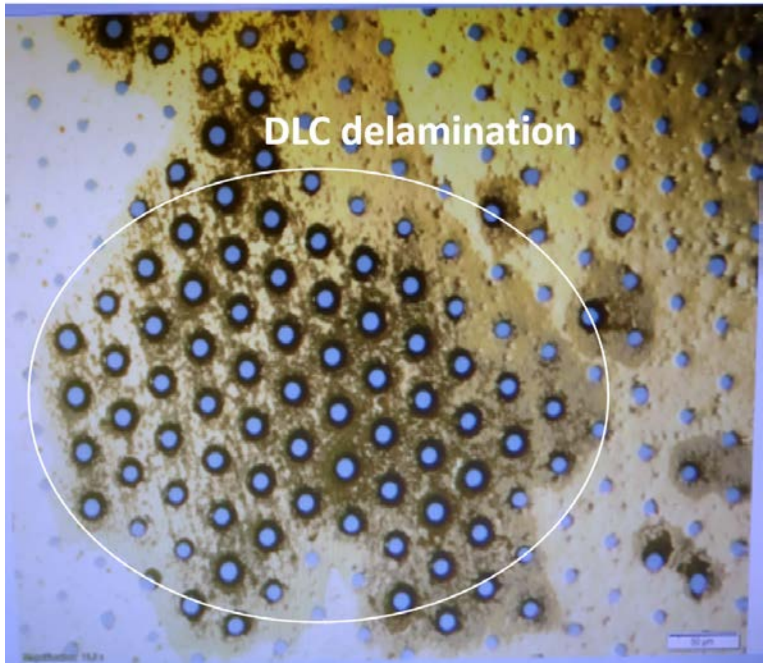
Goal of this project:

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.**

Preparation of resistive DLC on APICAL







Challenges

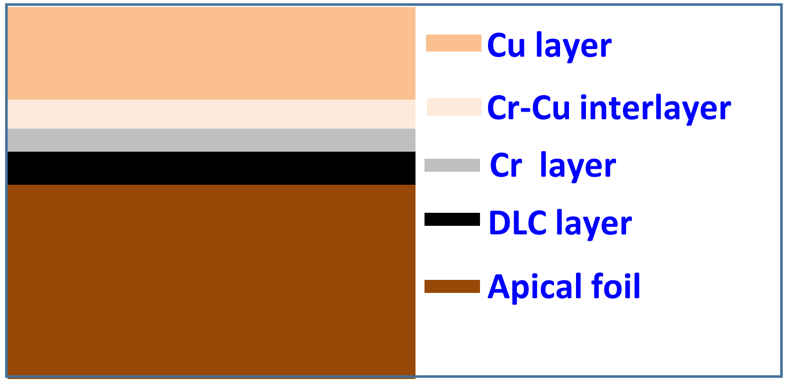
1. Inner stress caused the bending of the APICAL
2. How to control the resistivity;
3. Adhesion between the DLC/APICAL;

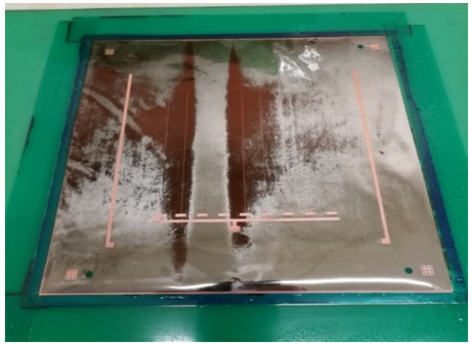
Solutions

1. Low bias voltage, high roughness of APICAL;
2. Vacuum degree, thickness, doping;
3. High roughness of APICAL;

Preparation Cr/Cu on DLC

Sample Clamping → Vacuum Pumping → Deposition DLC → Cooling in Vacuum → DLC Sample taking down → DLC sample Clamping → Vacuum Pumping → Deposition Cr → Deposition Cr-Cu → Deposition Cu → Cooling in Vacuum → DLC + Cu Sample taking down





Challenges

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

Solutions

1. Optimize the thickness of Cr layer, add Cr-Cu co-deposition layer, high bias voltage, high temperature, add DLC-Cr co-deposition layer, one-batch coating;
2. Optimize the thickness of each metal layer;
3. Extra Cu coating by galvanic method;

Current capacity of the sample production

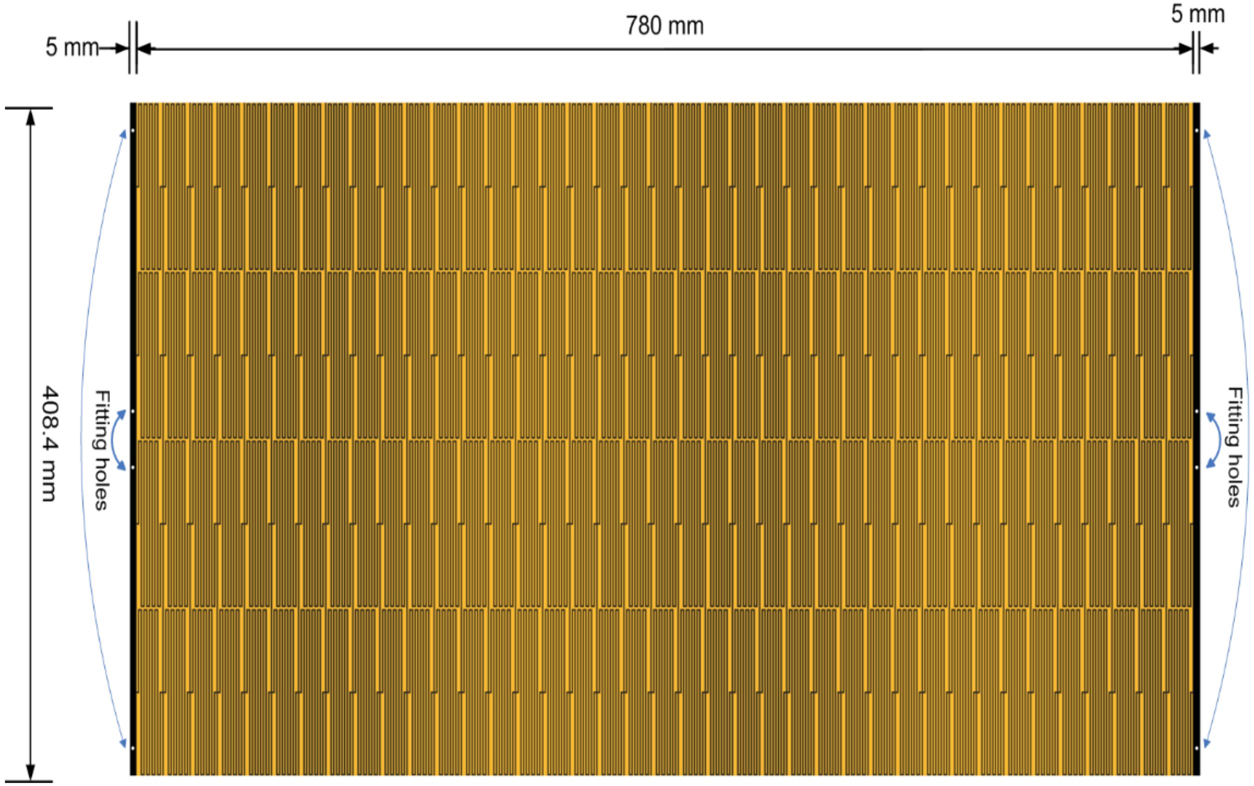
LICP & USTC

- 25cm×25cm DLC/DLC+Cu， coat DLC 1 per batch(80min), then coat Cr/Cu 5 per batch(9h);
- 120cm×60cm DLC/DLC+Cu, one by one (9h),
- High temperature(300℃) deposition (5h/11h);



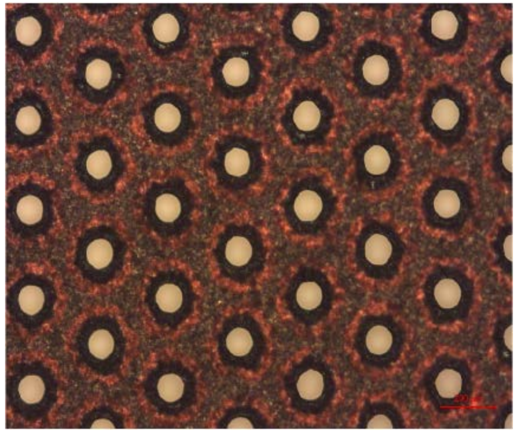

Kobe & Be-Sputter

- L×60cm DLC samples (L>100cm);
- Patterned(Lift-off) DLC foils with large size;
- Small size samples, many pieces in one batch;



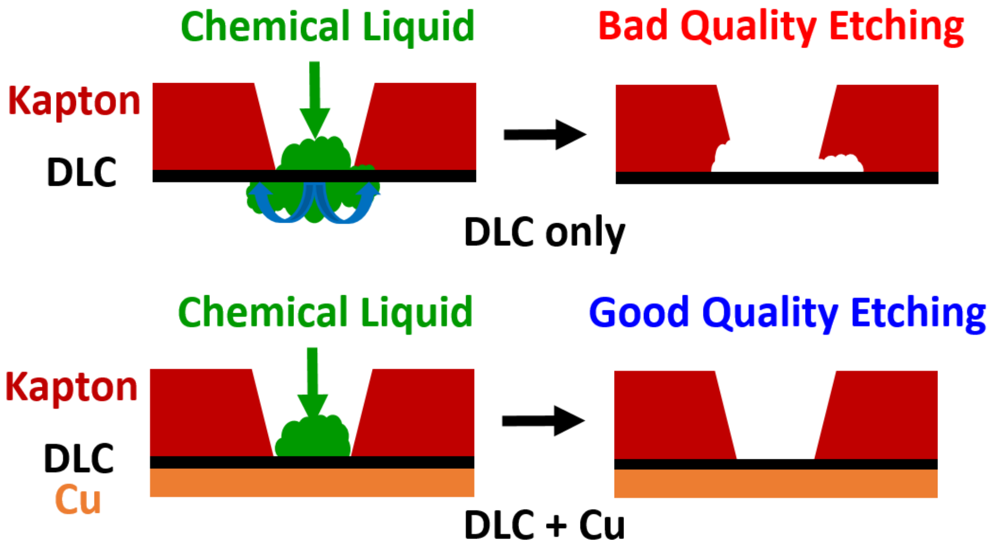
Resistive GEM and μRWELL-type FTM

Resistive GEM



FTM

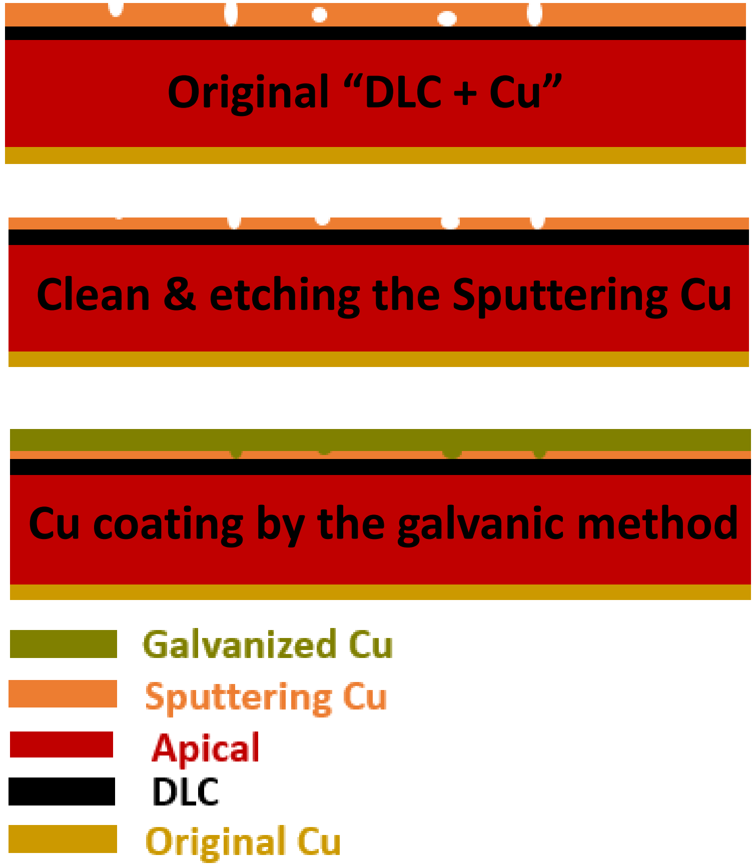
DLC+Cu improves the etching quality



Challenge:

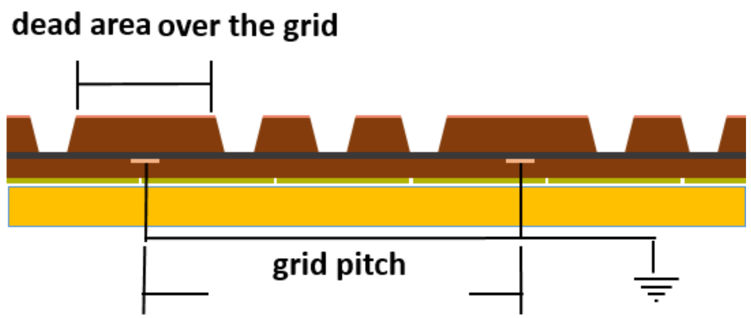
There are cavities inside the sputtered copper which leads the copper can't perfectly protect the APICAL during etching process;

Solution

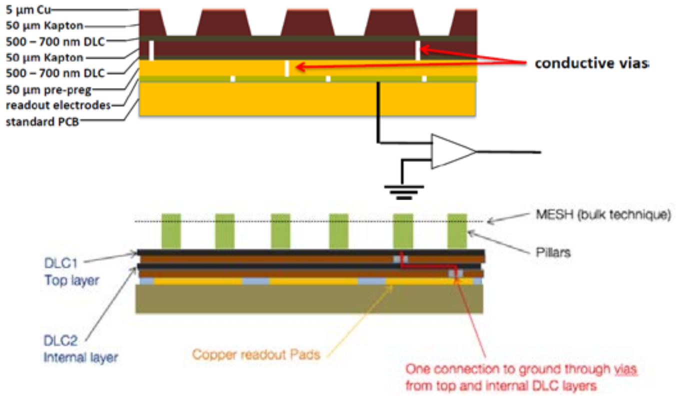


High rate µRWELL and MICROMEGAS

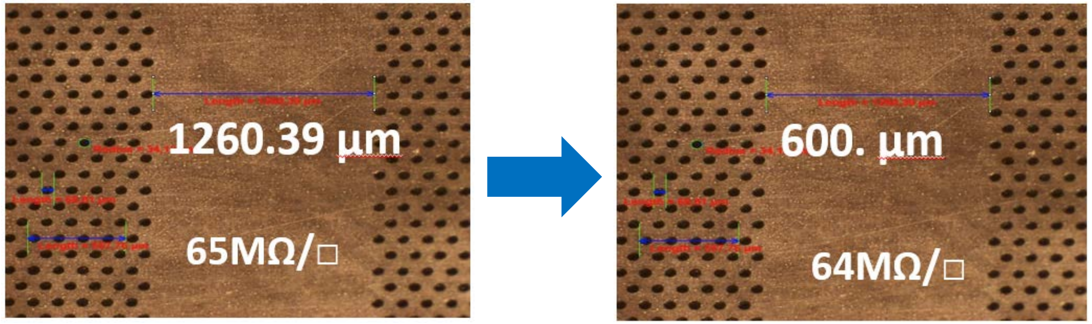
Fast grounding µRWELL



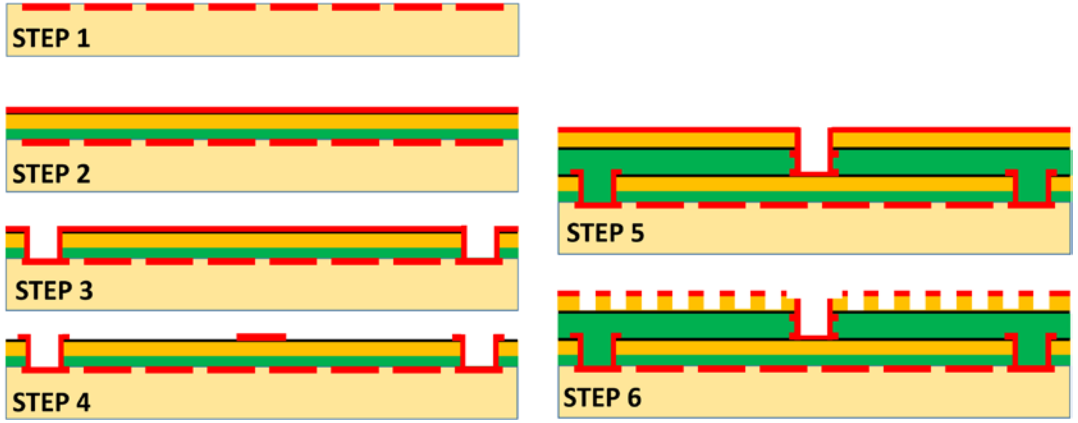
Double-layer µRWELL/Micromegas



DLC+Cu can decrease the dead area



DLC+Cu can simplify the manufacture process



Challenge:

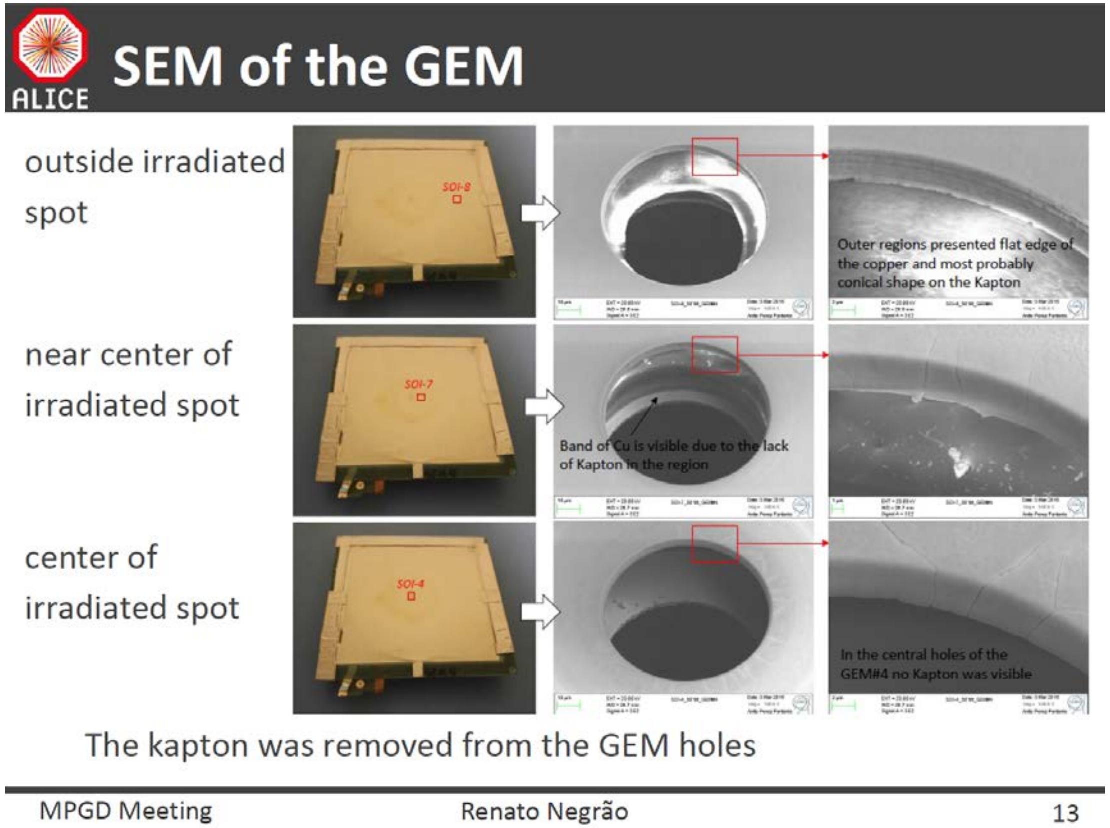
1. Resistivity decreasing after press gluing;
2. Cr/Cu delamination during drilling/etching;

Solution:

1. Make larger resistivity at the beginning as the compensation;
2. Improve the adhesion of the Cr/DLC;

GEM with thick-DLC (very high resistivity) in Holes

Kapton Etched during GEM operation



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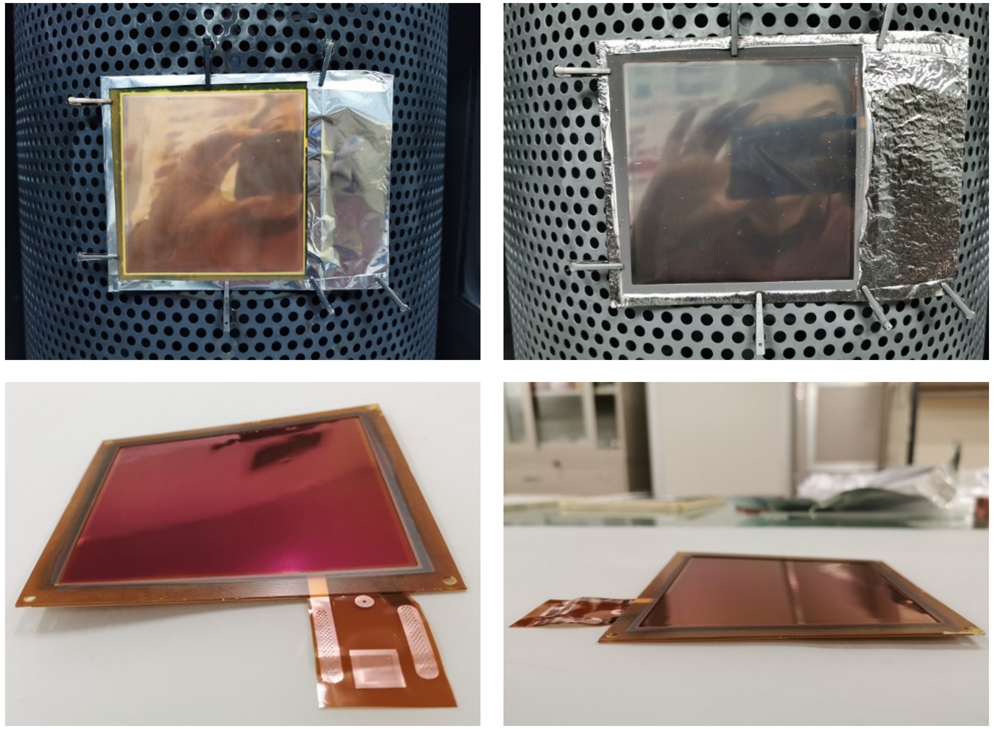
Coating DLC in holes to protect the Kapton



Challenge:

Large inner stress caused the foil bending

The foils are waiting for test and we are looking for a way to decrease the inner stress

Conductive DLC for low mass GEM

➢ By applying high vacuum, large thickness and element doping, we can greatly decrease the resistivity of the DLC

Batch No.	Substrate	Vacuum (10^{-5} Torr)	Current(A)	Cr & Cu Current(A)	Time(min)	Resistivity (Ω/□)
8-27-06	FR4	1.4	3.5	0	80	180k
9-01-01	FR4	1.4	3.5	0.3	80	350
8-24-01	APICAL	0.06	2.8	0	30	36k

Challenge:

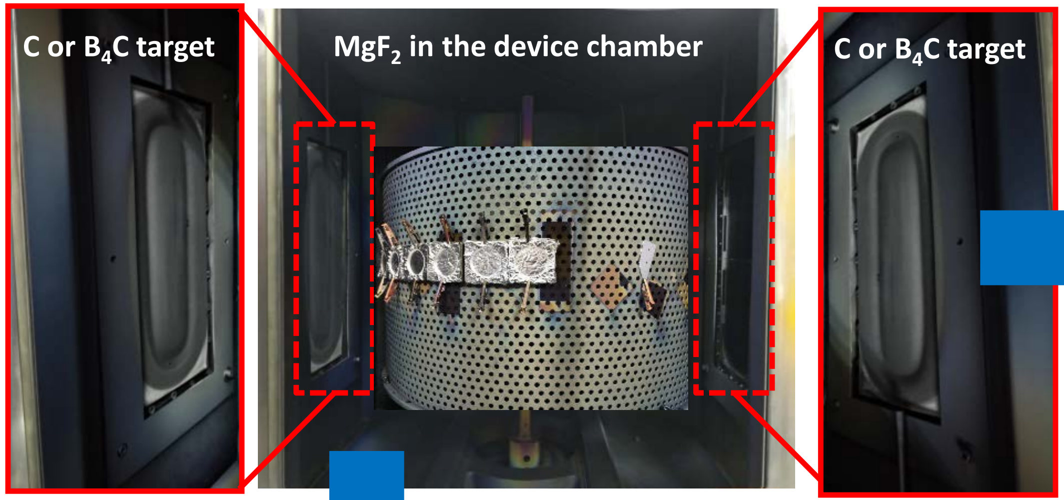
1. Etching though the thick DLC is not perfect yet;
2. In some applications(X-ray fluorescence analysis), metal doping is not a good way;

Possible solution:

1. Improving the etching process;
2. Try to doping nonmetal element: Nitrogen, Boron;
3. High temperature coating;

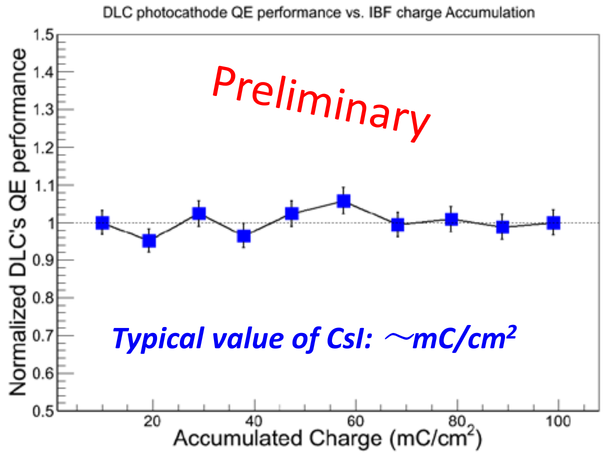
DLC on MgF_2—Robust photocathode

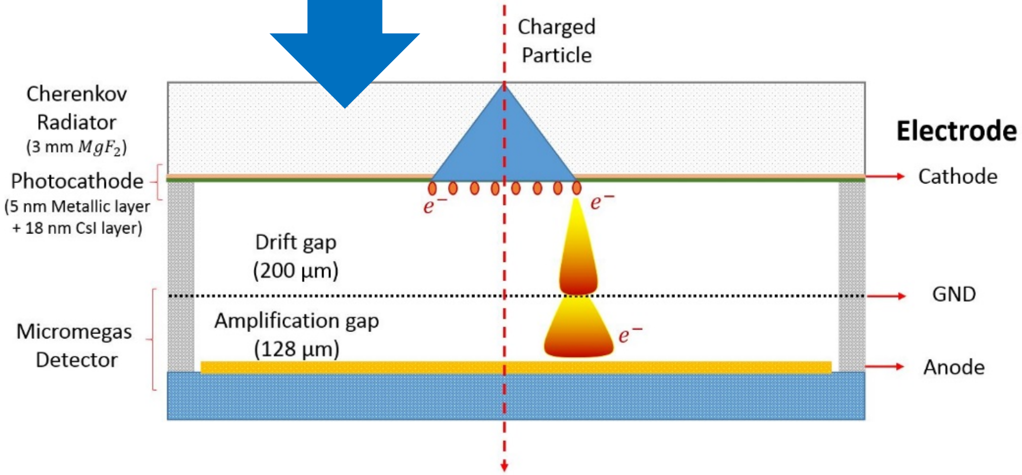
DLC photocathode for PICOSEC-MICROMEGAS



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





Challenges:

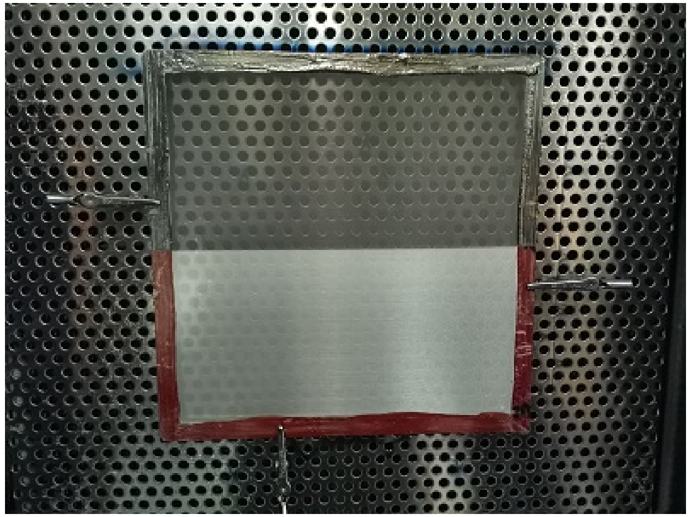
- Optimization of thickness;
- Optimization of the sp^3/sp^2 ratio;
- Optimization of the energy band;
- Surface treatment (No hydrogenation);

Solutions:

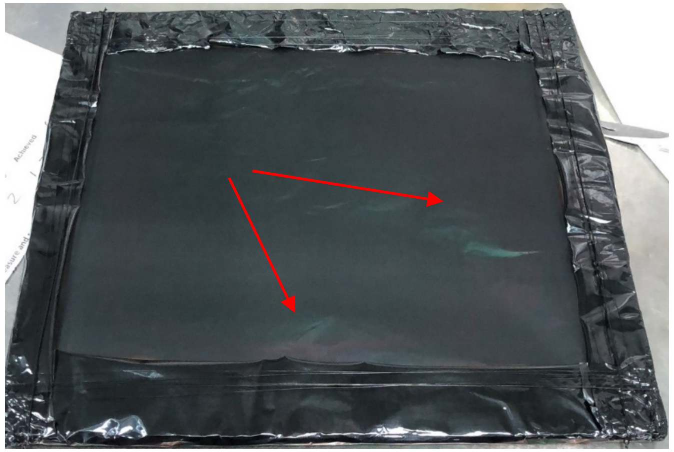
- Thickness scan;
- PLD, Cathodic arc, and other method;
- Boron doping;
- Metallic oxide deposited on surface by ALD (1st attempt was failed…);

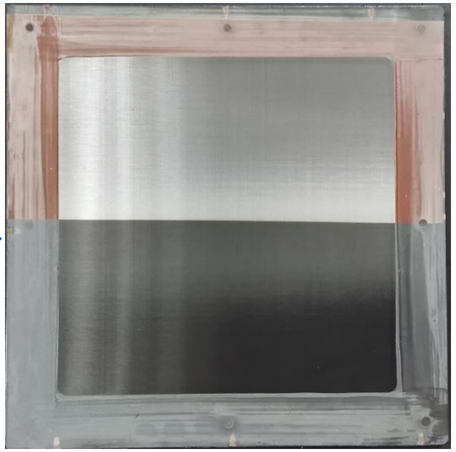
DLC on stainless steel mesh—Black mesh

Black mesh for MICROMEGAS with optical readout (IRFU/DPhN, CERN, USTC, LICP)



Color of different Hydrogen doping





Advantages of the black mesh: Less reflection photons

- In detector manufacture: less reflected UV light and provide a shaper edge between exposed & non-exposed coverlay, then the etching chemical remnants in amplification zone will be lessened, and this will yield a more stable MM operation.

- In application: less reflected visible light can decrease the defusion of the image captured by the camera, thus minimize the degration of image definition.

Challenges:

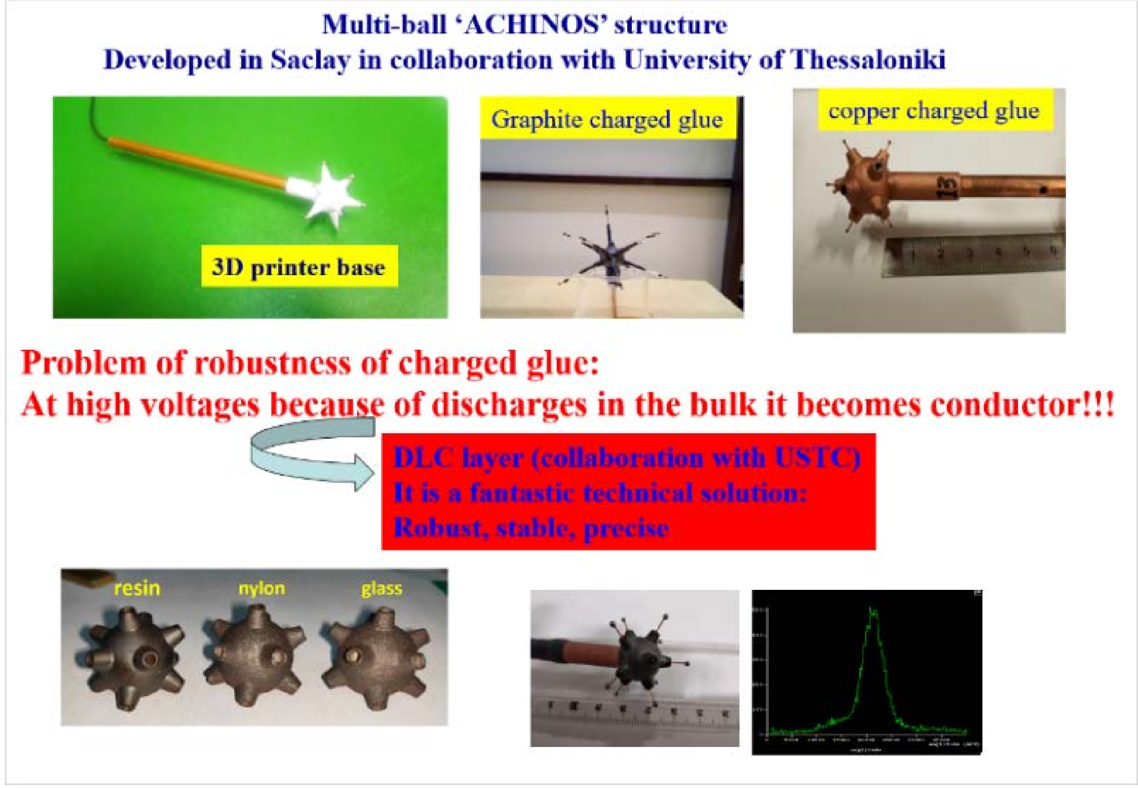
- Bad hydrogen doping will cause colorful colors;
- Much worse adhesion compared with the DLC on stainless steel disc；

Solutions:

- Optimize the amount of hydrogen doping;
- Add DLC-Cr co-deposition layer;
- High temperature coating, PSE pre-process for mesh clean

DLC on spherical resin—Resistive ACHINO

Resistive ACHINOs for the spherical detector



https://indico.cern.ch/event/843711/contributions/3607162/attachments/1930459/3197217/RD51-19.pdf

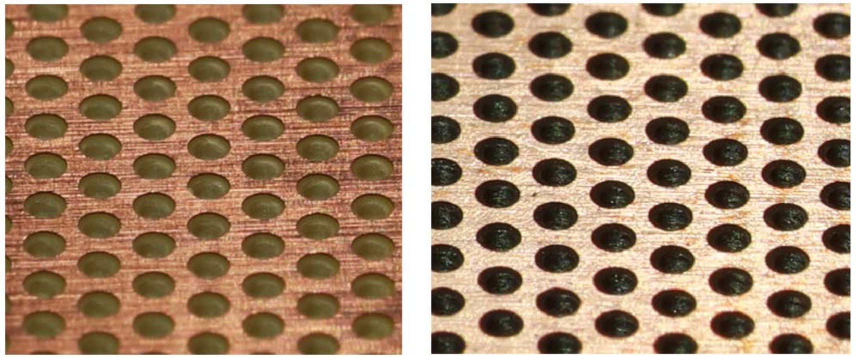
DLC coating

Challenge: Uniformity is bad (but not important)

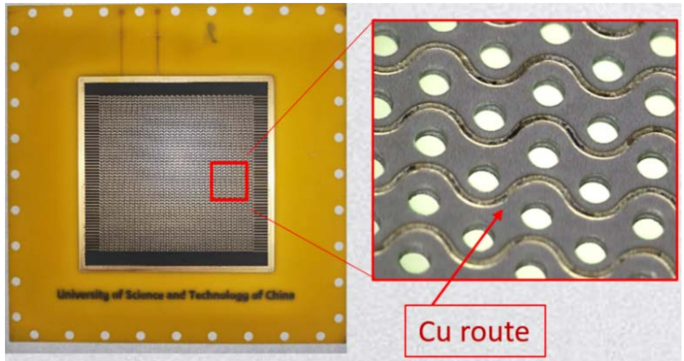
Solution: Multi-coating if necessary

DLC on PCB—RTGEM based detectors and μ-PIC

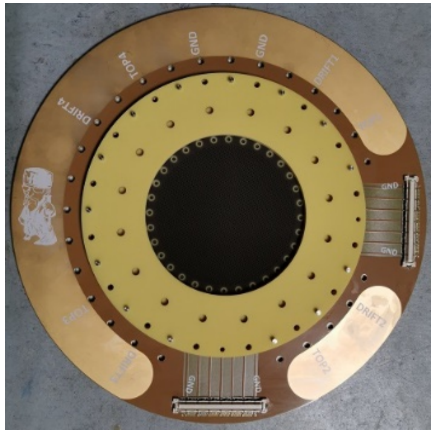
Charging-up free THGEM



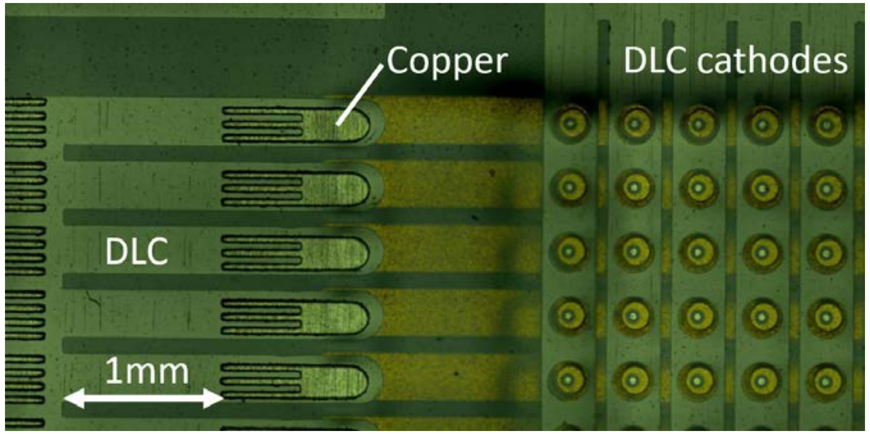
Resistive THGEM



RWELL-type FTM



μ-PIC



Challenges:

1. Difficult to coat DLC on copper;
2. Operating temperature should be below 200℃;
3. Multi-time lift-off takes very long time;

Solutions:

1. Use lift-off to coat Cr before DLC coating;
2. Try to avoid high temperature operating;

Resistivity decreasing caused by heating

➢ The DLC will be heated during the copper coating and detector manufacture

Resistivity decreasing of normal DLC+Cu

Batch No.	R1(MΩ/☐)	R2(MΩ/☐)	Ratio
8-26-3	150	3.8	39.5
8-25-4	150	27	5.6
6-27-5	115	7.2	16.0
6-27-3	80	7.5	10.7
8-25-7	150	20	7.5
8-25-2	100	20	5.0
8-26-1	160	28	5.7
8-26-6	240	43	5.6
8-26-7	140	18	7.8
8-25-5	140	25	5.6
8-24-6	200	34	5.9
8-26-4	120	33	3.6
8-25-4	150	54	2.8
8-24-5	180	32	5.6

I doubt the Cr is not fully etched on this sample!

Resistivity decreasing of low resistivity samples

Batch No.	R1(kΩ/☐)	R2(kΩ/☐)	Ratio
8-28-4	342	32.7	10.5
8-27-1	340	44	7.7

Resistivity decreasing of double-side samples

Batch No.	R1(MΩ/☐)	R2(MΩ/☐)	Ratio
8-29-9	1400	340	4.1
8-27-4	75	17	4.4
8-29-8	750	550	1.36
8-27-3	450	89	5.1

Unknown reason

To be checked systematically:

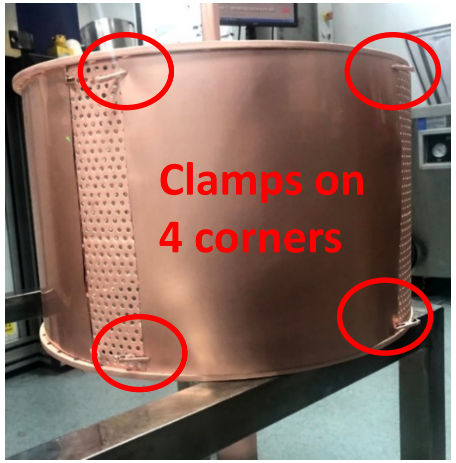
➢ If the resistivity decreasing varies with the roughness of the APICAL;
➢ If the resistivity decreasing varies with different resistivity value;

Calibration plan for resistivity decreasing

- ➢ We will use the vacuum oven to calibrate the resistivity decreasing under 200℃ for 5 hours
- ➢ We can measure the same position with the same pressure before/after heating

Adhesion of Cr/DLC test and next work plan

- Delamination occurred during detector manufacture due to bad adhesion



Roughly Rank of the adhesion:

Base material :	→ reference 100 %	→ really good
DLC+Cu coating under 300℃:	→ 80% of the reference	→ good
Center of normal DLC+Cu:	→ 50%	→ medium, but good enough for fast grounding
Outer part of normal DLC+Cu:	→ 20%	→ not sufficient for processing

Current problem:

1. For the normal samples, the adhesion of the center area is better than it of the outer area;

2. For high temperature deposition (300℃), the resistivity is hard to control, and we don't know if it can be removed by alcohol (on glass, yes)

Possible reason:

1. The sample is fixed by 4 clamps on the 4 corners, these clamps changed the electric field and caused the different adhesion;

2. We have metal at the edge area, the edge effect caused the different adhesion;

3. High temperature deposition produced a lot of *sp*^{2} structures inside the DLC;

Next work:

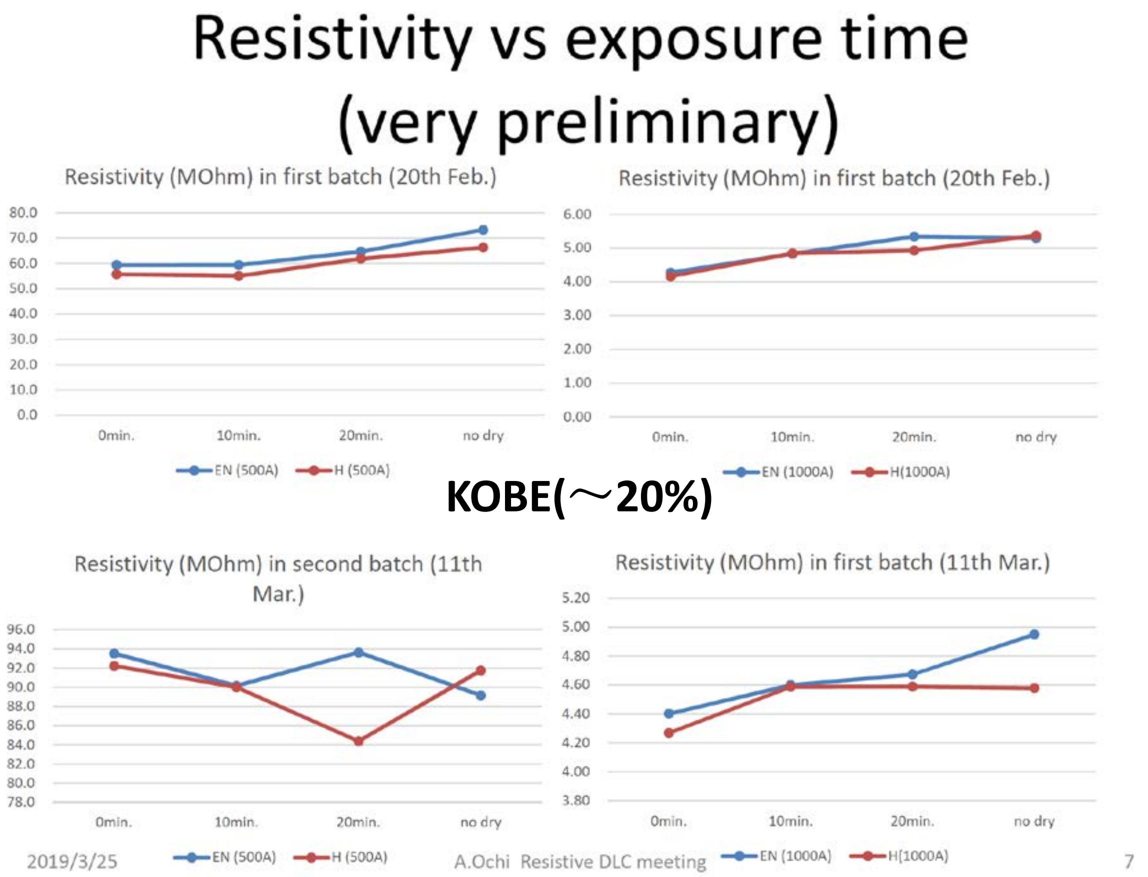
1. Try to use the Teflon screw to fix the sample then check the adhesion;

2. Use larger size samples to see if the worse adhesion area moves far away from the center;

3. We have to check if the alcohol can remove the high temperature DLC on APICAL;

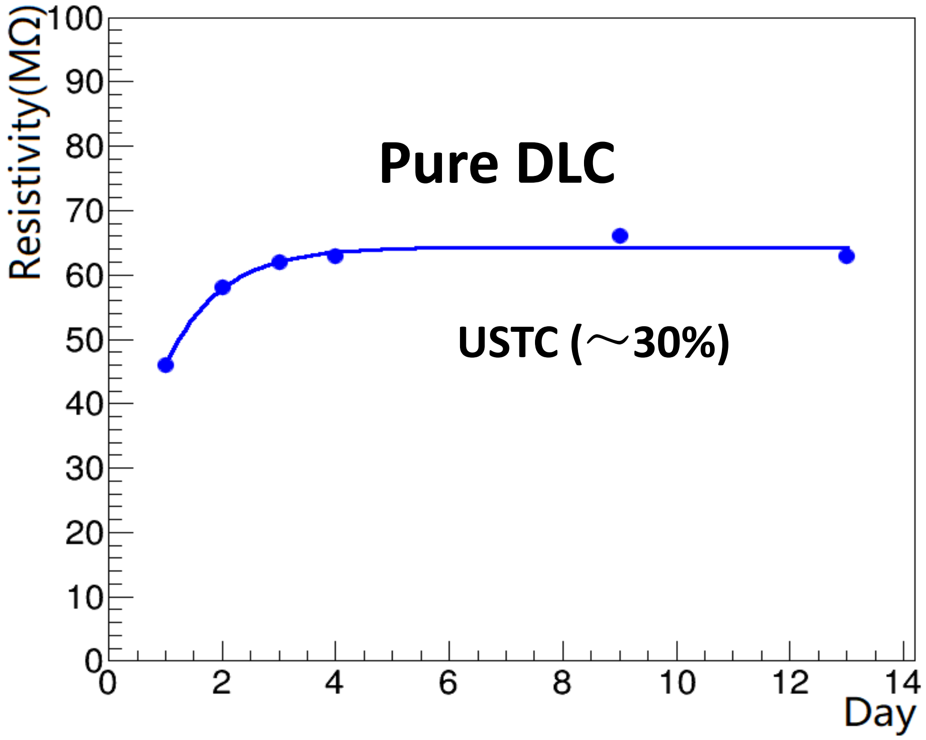
Passivation in air after sputtering

➢ To estimate the resistivity change before sputtering



KOBE(～20%)

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



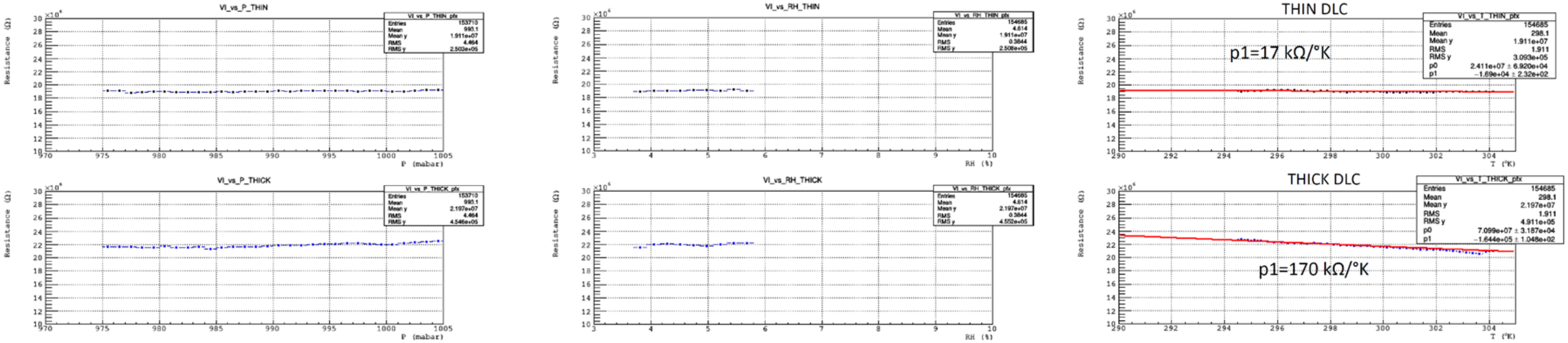
➢ DLC resistivity will increase in air after it was take out from the sputtering chamber;

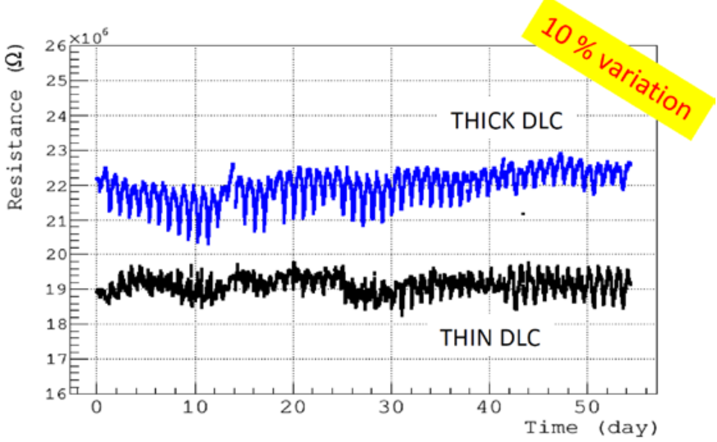
➢ The test results are more or less compatible with USTC results;

Stability in air

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

Resistive .VS. Pressure | **Resistive .VS. Humidity** | **Resistive .VS. Temperature**



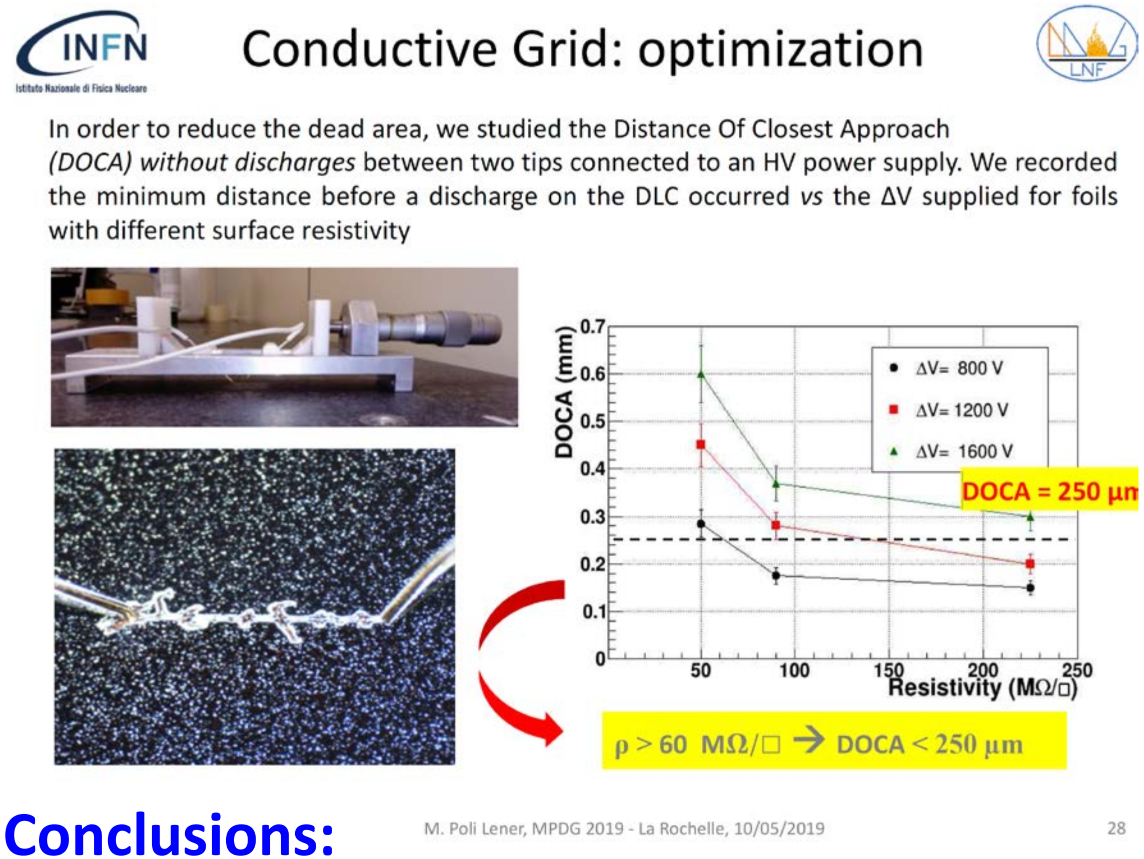


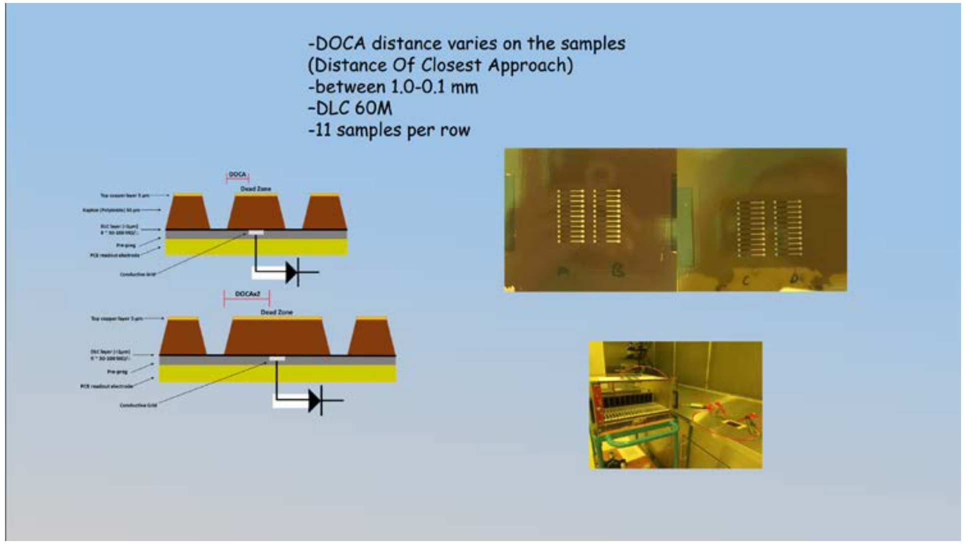
Conclusions:

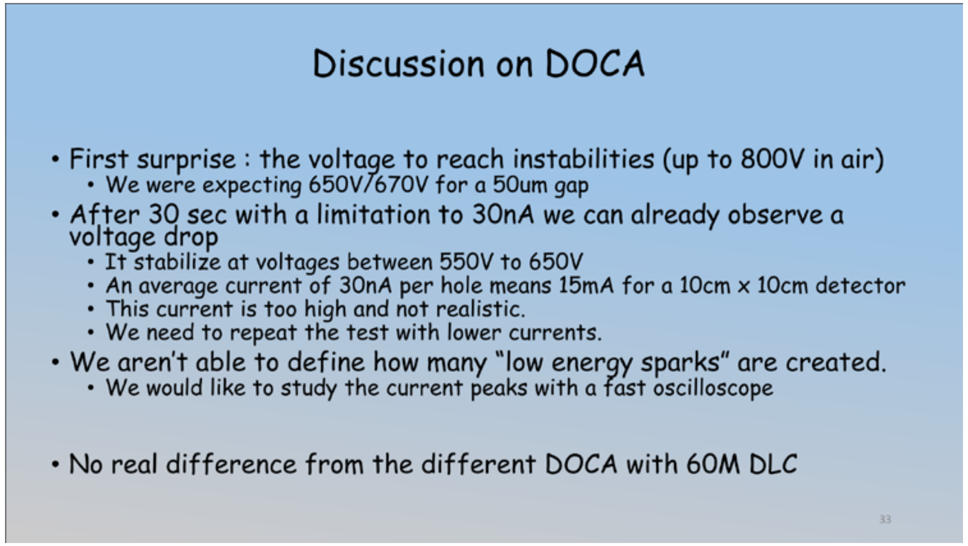
- The DLC resistivity is not sensitive to the pressure and humidity;
- The DLC resistivity will decrease when the temperature increase, more systematically measurement should be done in future;
- DLC has a very good long term stability in air;

The DOCA measurement

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







Conclusions:

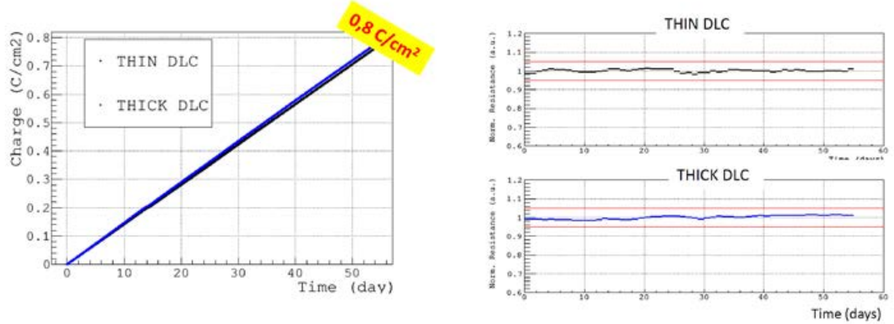
➢ **250µm is safe enough for resistivity larger than 60MΩ/□;**

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

The aging measurement

➢ **To make sure the DLC is radiation hard**

DLC stability under current drawing

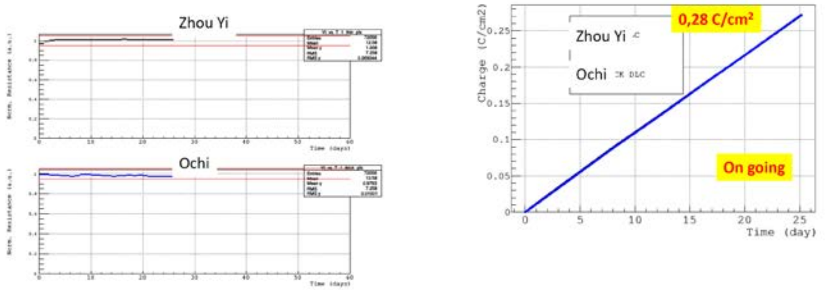


No effects obsserved after an integrate charge of ~ 1 C/cm²

DLC stability under current & X-ray

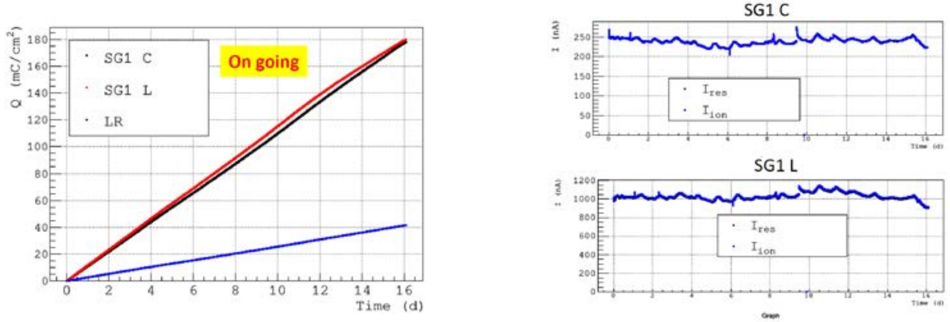
Similar setup of the previous measurement + X-ray gun irradiating the DLC surface

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



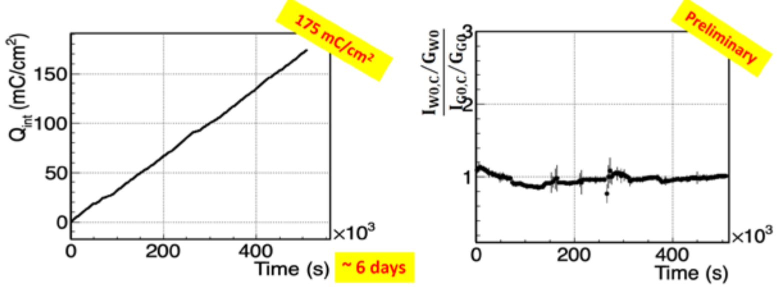
Detector aging: X-Ray LNF

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 .

Thanks

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