MPGD 2019

LA ROCHELLE

Development of high-performance DLC resistive electrodes for MPGDs

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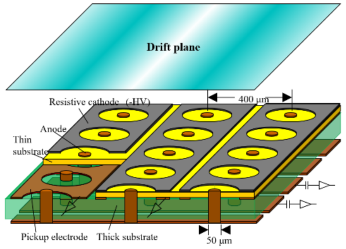
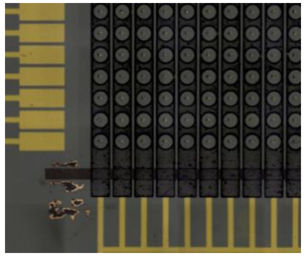
Chinese Academy of Sciences

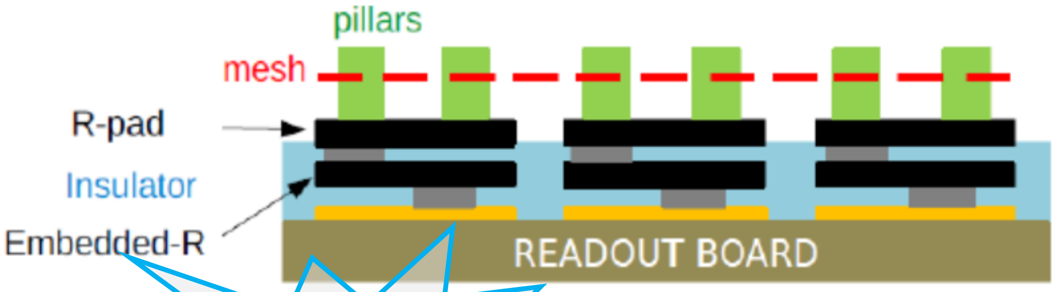
On behalf of the resistive DLC collaboration

Motivation

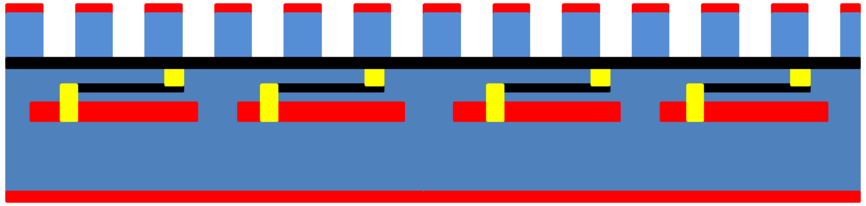
Resistive materials based on Carbon loaded pastes have already widely used in MPGDs to suppress the discharges and reduce the damaging effects on MPGDs

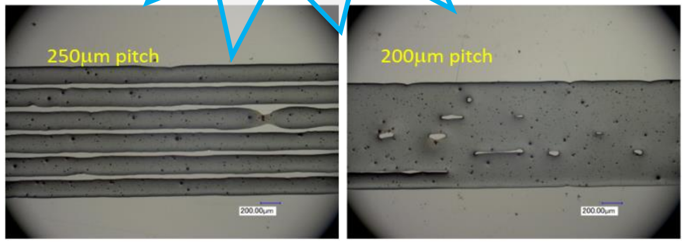


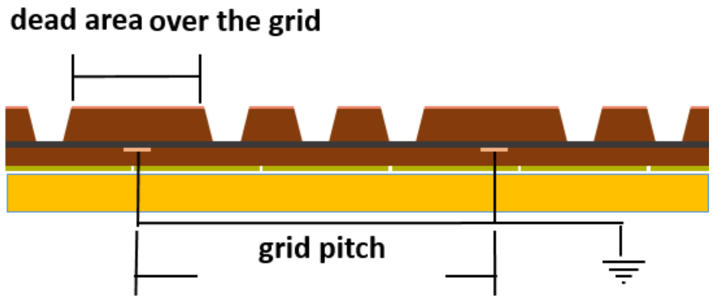




However





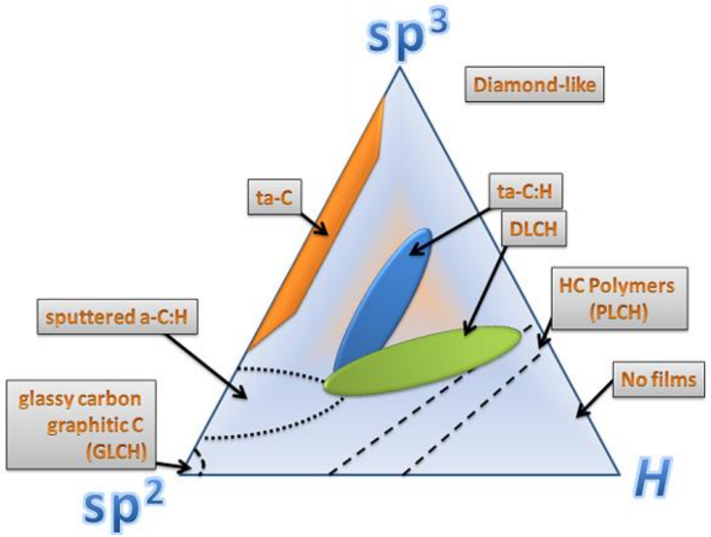


- × *Resistivity sometimes out of control in manufacture;*
- × *Unable to make fine structures;*
- × *Difficult to make conductive route on it precisely;*
- × *Can not open opportunities for new micro-structures;*

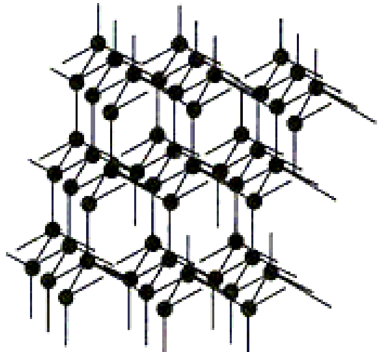
New reliable resistive materials and preparation methods needed

A solution: Diamond-Like Carbon (DLC)

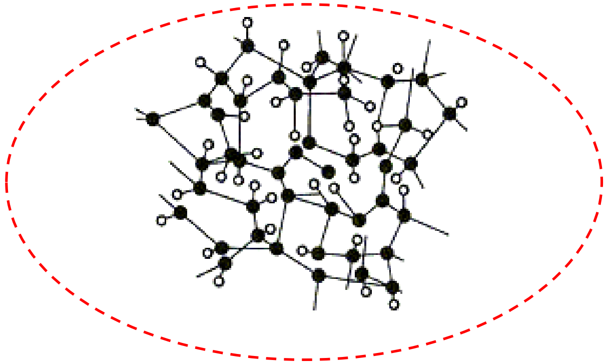
DLC is a type of amorphous carbon which contains both graphite structure (sp^2) and diamond structure(sp^3)



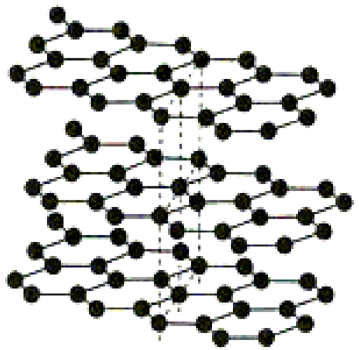
- ✓ *Robust and stable, excellent chemical and physical inertness*
- ✓ *Sub-micrometer thickness, easy to make fine resistive structures;*
- ✓ *Surface resistivity can be precisely adjusted by changing the sp^2/sp^3 ratio or element doping；*
- ✓ *Allow to make precise routes by using photolithography*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



Diamond structure



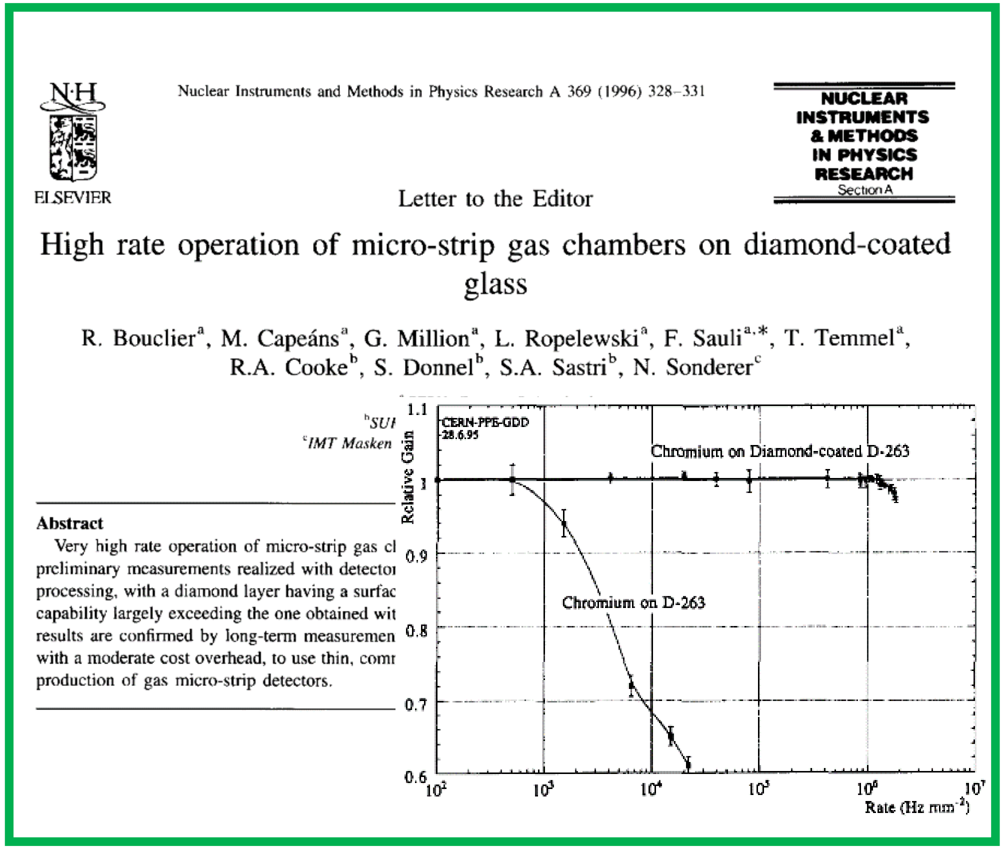
DLC structure



Graphite structure

Pioneering DLC applications on MPGD

High resistivity *(～10^{14}Ω/☐) DLC was applied on the MSGC by GDD in 1996*


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

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

ELSEVIER

Letter to the Editor

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

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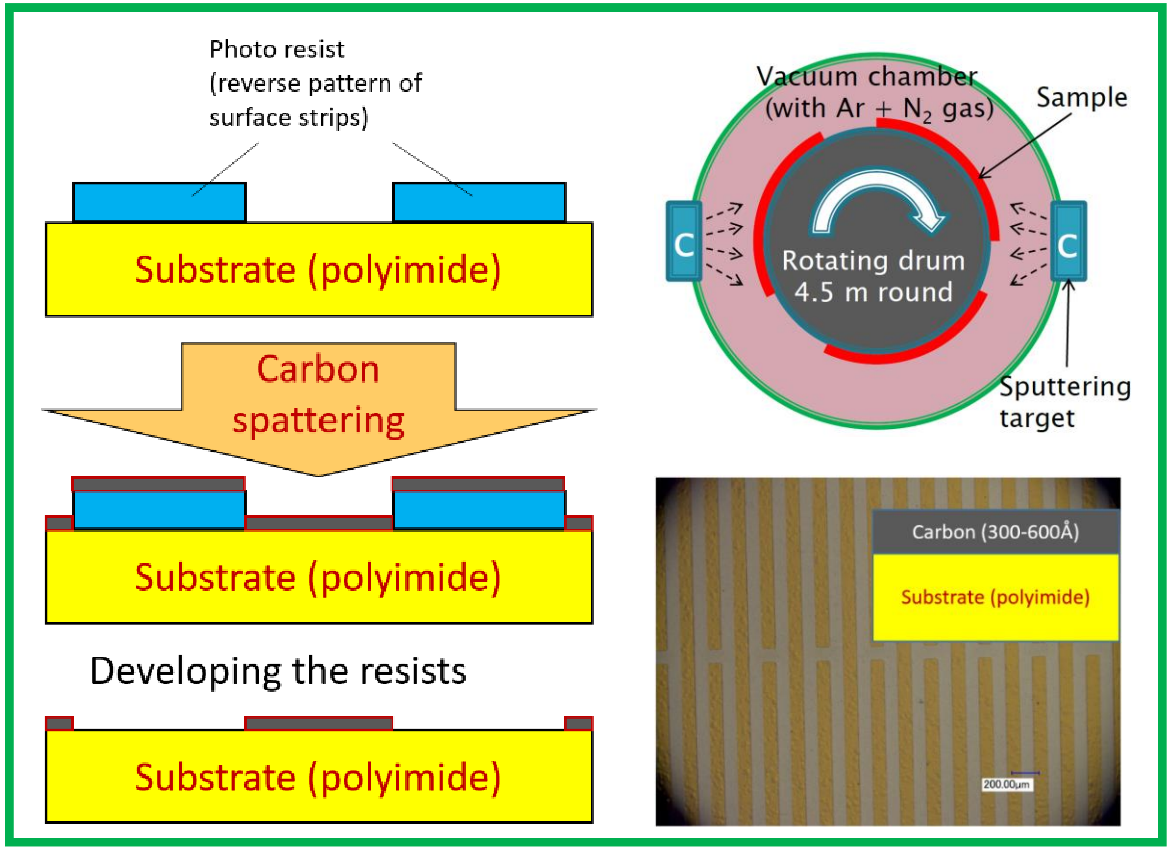
[b]SUI
[c]IMT Masken

Abstract

Very high rate operation of micro-strip gas cl preliminary measurements realized with detector processing, with a diamond layer having a surfac capability largely exceeding the one obtained wit results are confirmed by long-term measuremen with a moderate cost overhead, to use thin, comr production of gas micro-strip detectors.

Resistivity *DLC (～MΩ/☐) was applied on the Micromegas by A.Ochi in 2013*



- ✓ ***Charging up removed;***
- ✓ ***Rate capability greatly improved;***

- ✓ ***1MΩ/☐ 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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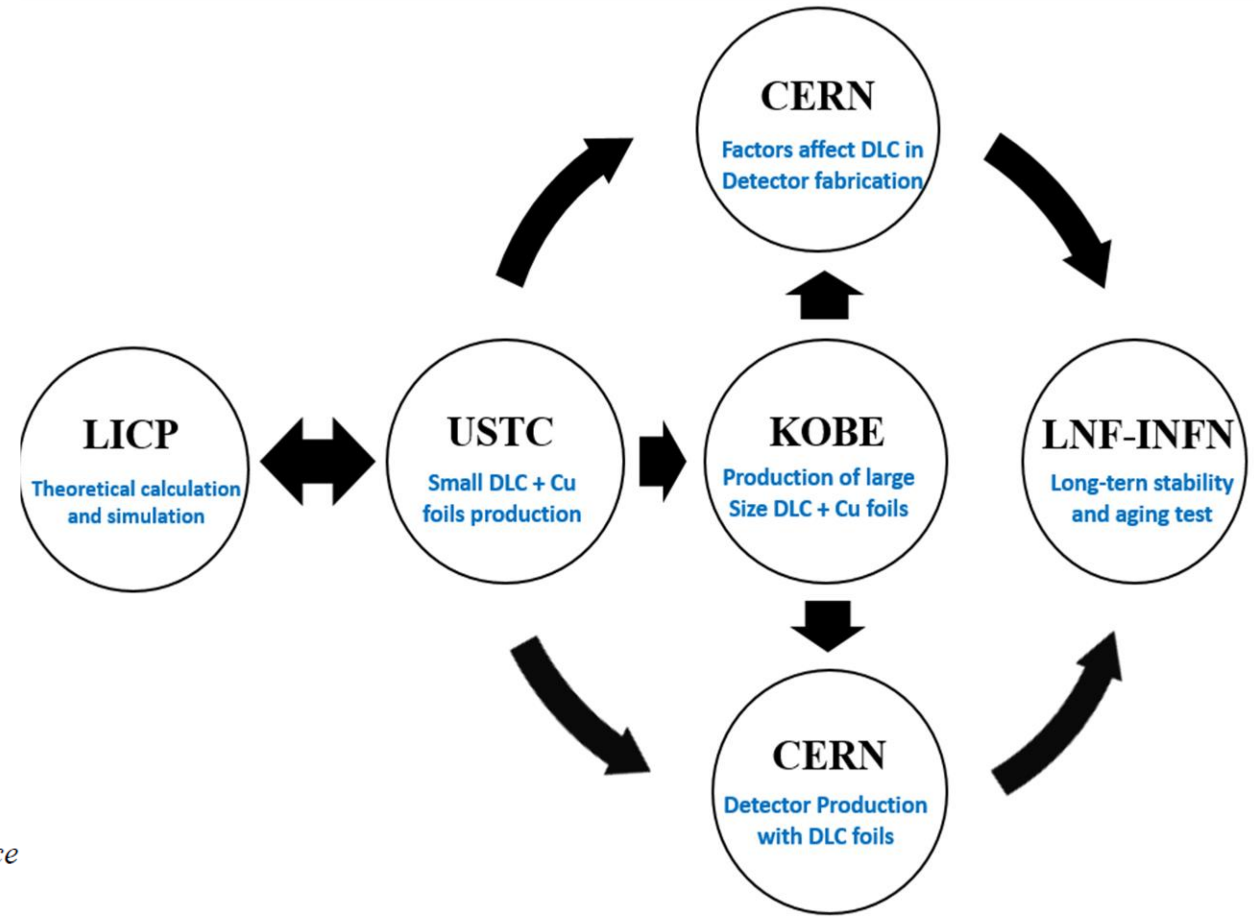
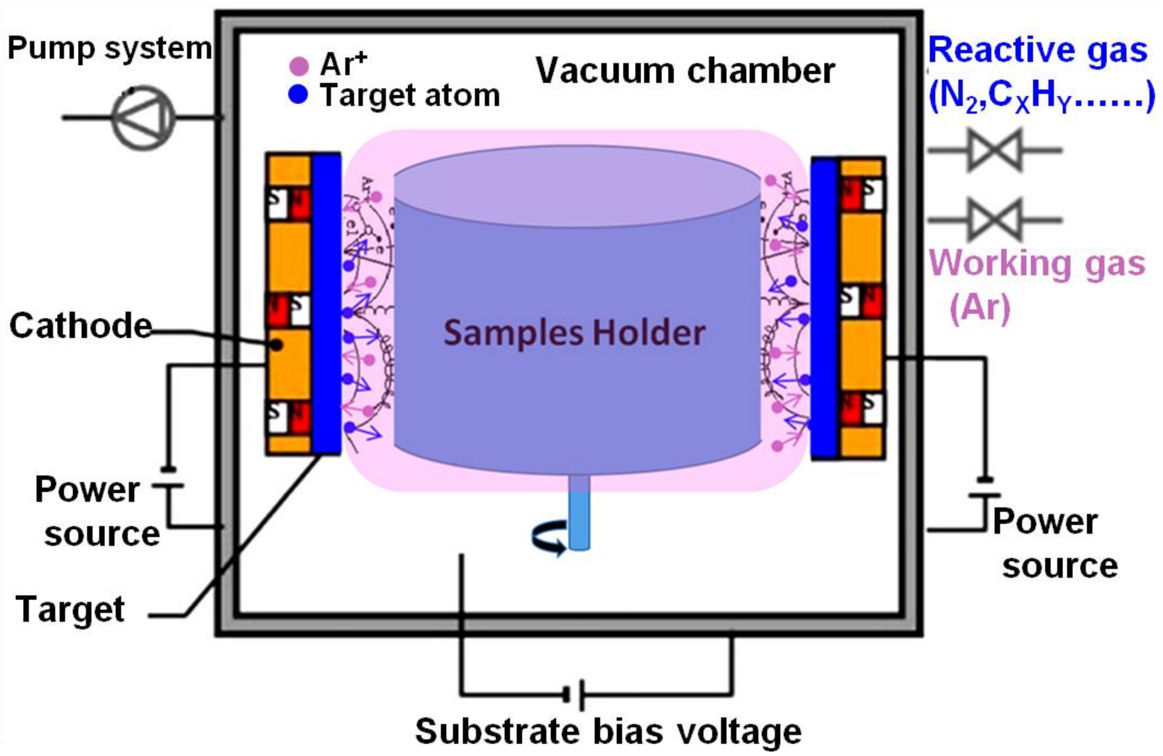


Hybrid Physical-Chemical Vapor Deposition (HPCVD)



- *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 —On Apical→ Control the resistivity → μRWELL, MicroMegas

➢ Thick DLC

Cover the rough surface —On PCB→ Control the resistivity → THGEM, RPWELL

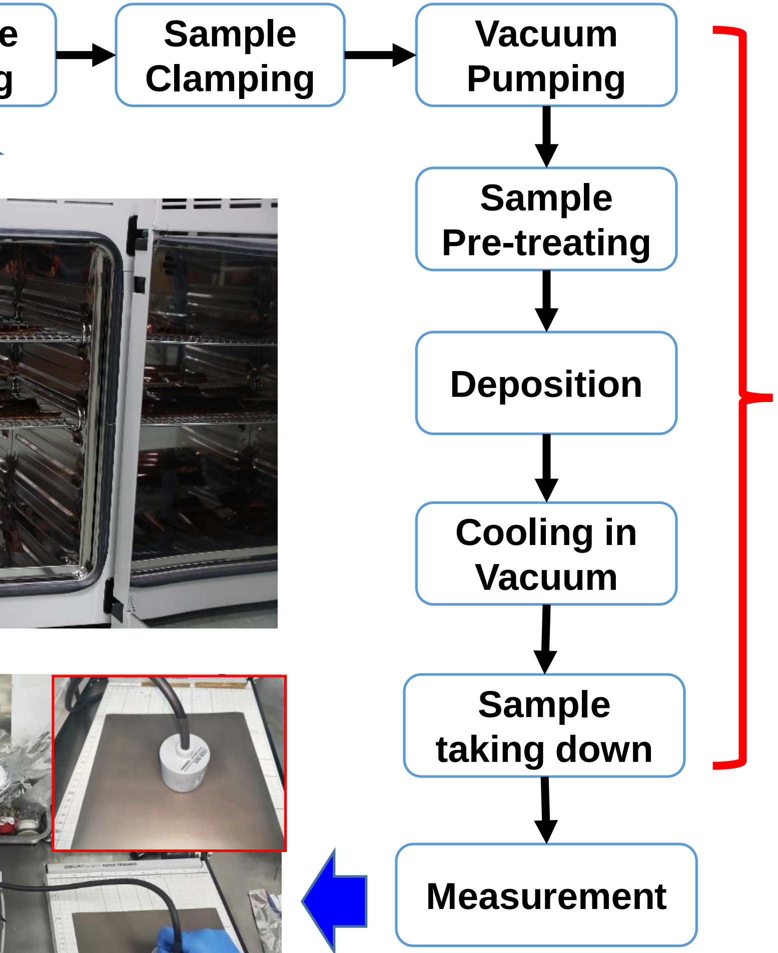
➢ New type of "DLC+Cu"

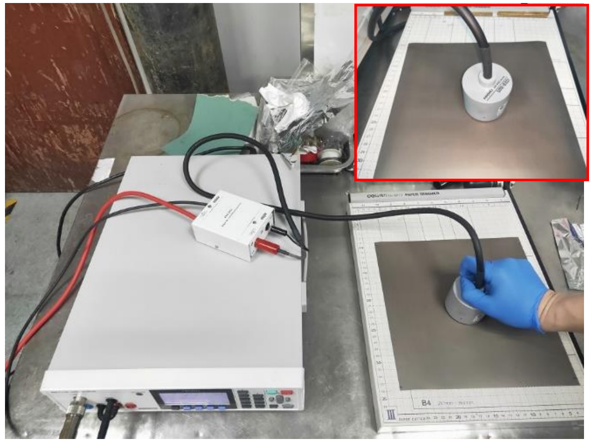
Manufacture precise circuit —On Apical→ Control the resistivity → New MPGDs

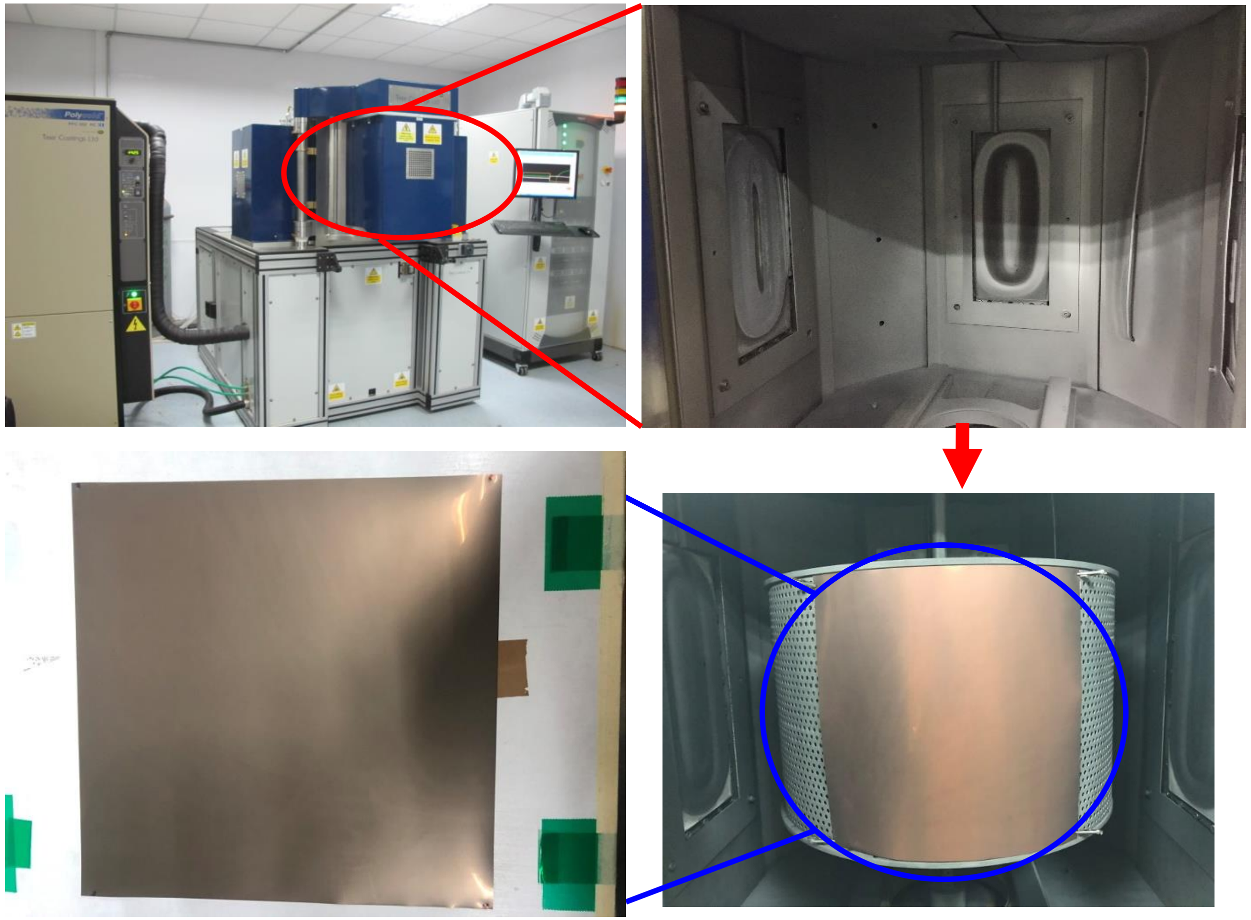
➢ DLC as photocathodes

Photoelectric properties —On MgF_2→ B-doped, controlling the SP^3 → PICOSEC MicroMegas

Thin DLC on APICAL



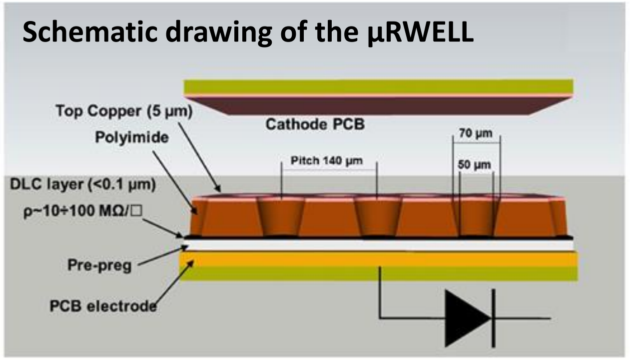




- *Resistive DLC prepared by magnetron sputtering the high purity graphite targets*
- *Resistivity controlled by adjusting target power, deposition time, vacuum degree, and so on.*

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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[a]*Laboratori Nazionali di Frascati dell'INFN, Frascati, Italy*
[b]*CERN, Meyrin, Switzerland*

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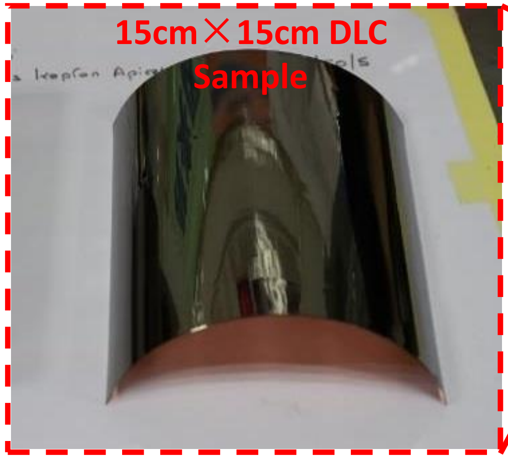
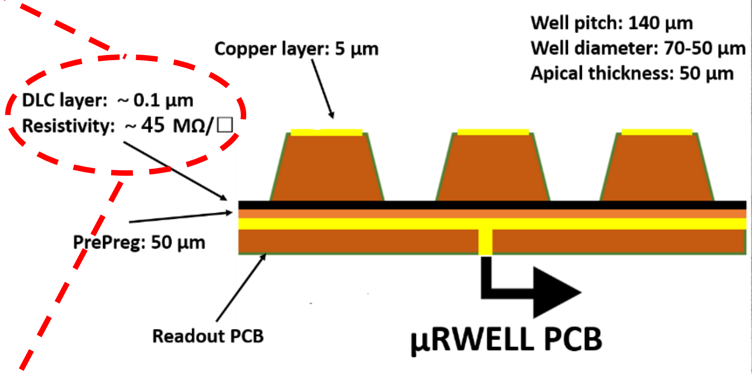
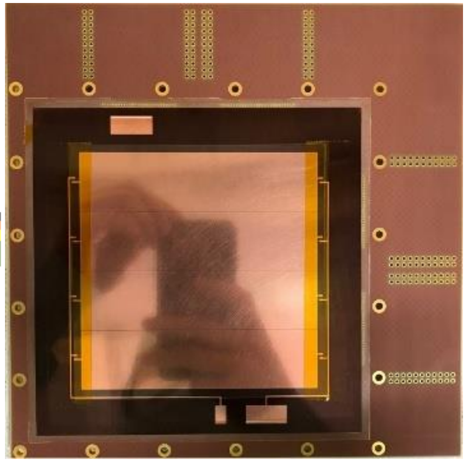
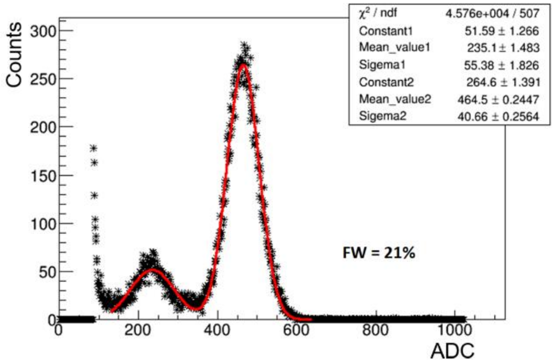
ABSTRACT: In this work we present a novel idea for a compact spark-protected single amplification stage Micro-Pattern Gas Detector (MPGD). The detector amplification stage, realized with a structure very similar to a GEM foil, is embedded through a resistive layer in the readout board. A cathode electrode, defining the gas conversion/drift gap, completes the detector mechanics. The new structure, that we call micro-Resistive WELL (µ-RWELL), has some characteristics in common with previous MPGDs, such as C.A.T. and WELL, developed more than ten years ago. The prototype object of the present study has been realized in the 2009 by TE-MPE-EM Workshop at CERN. The new architecture is a very compact MPGD, robust against discharges and exhibiting a large gain ($\sim 6 \times 10^3$), simple to construct and easy for engineering and then suitable for large area tracking devices as well as huge calorimetric apparata.

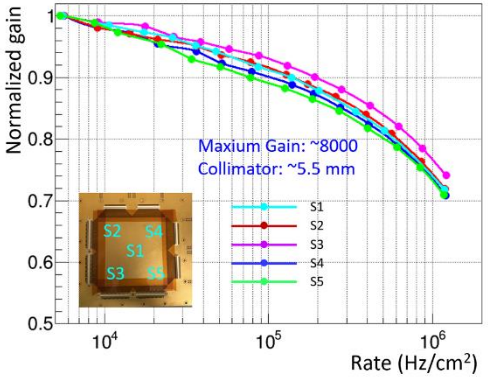
µRWELL detector's idea

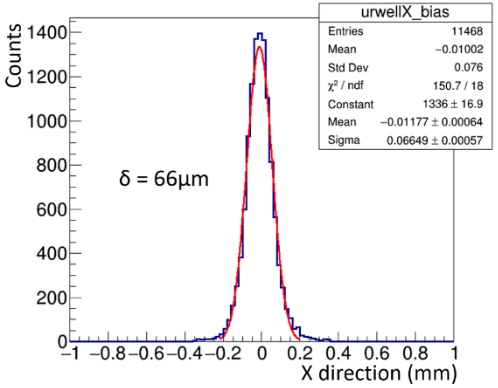










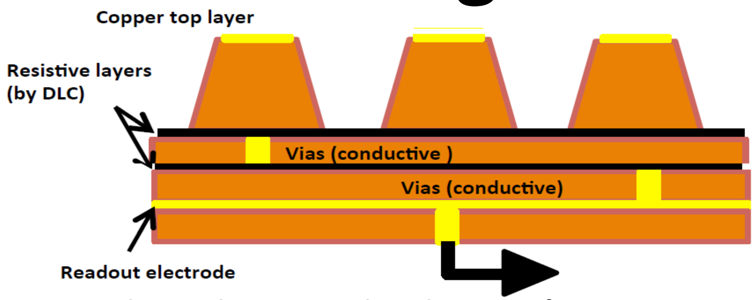


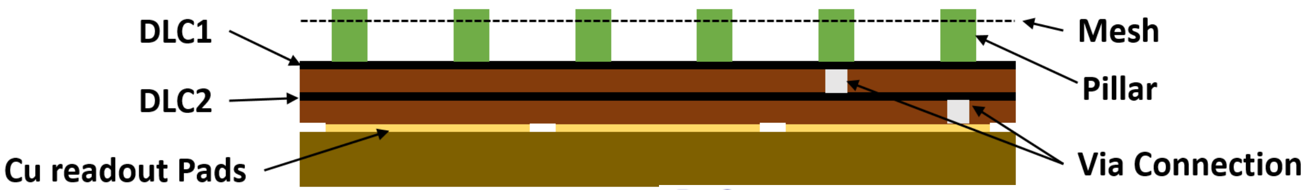
- ✓ *Energy resolution: ~21%@8keV X-ray*
- ✓ *Rate capability: gain drop<10% @100kHz/cm^2*
- ✓ *Spatial resolution: <70 µm @150GeV/c muon*

Zhou Y, Lv Y, Shang L, et al. Nucl.Insr.Meth.A.927(2019)31

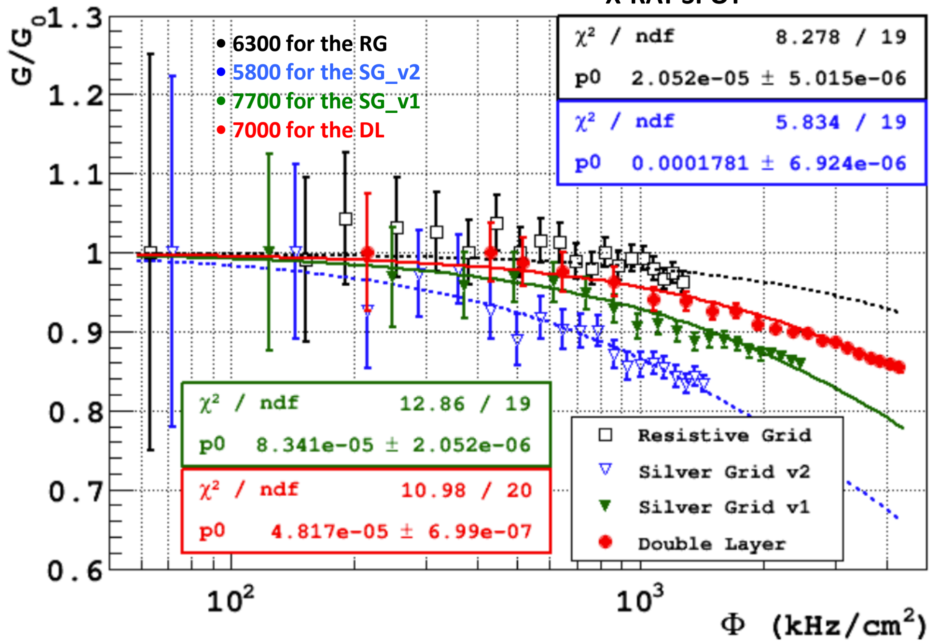
Application 2

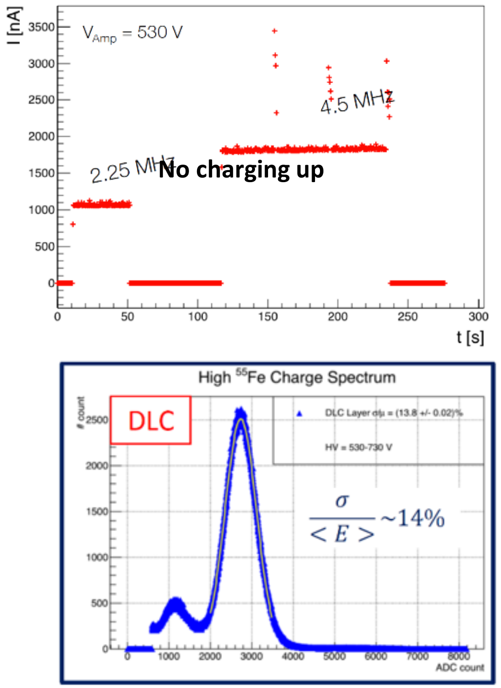
High rate μRWELL and MicroMegas

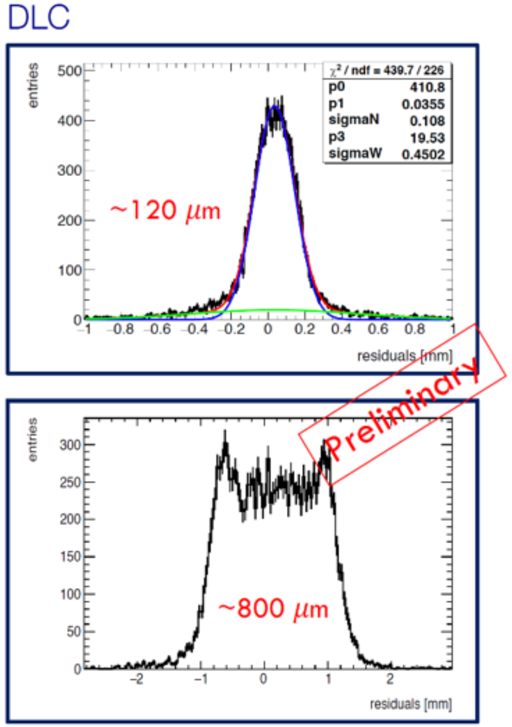




Ar/CO2/CF4=45/14/40 & $Ø_{X\text{-}RAY\ SPOT}$ ~ 4 cm







✓ *High rate capability (>1MHz/cm²)*

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

✓ *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 —(On Apical)→ Control the resistivity → μRWELL, MicroMegas

- **Thick DLC**

Cover the rough surface —(On PCB)→ Control the resistivity → Resistive THGEM, RWELL

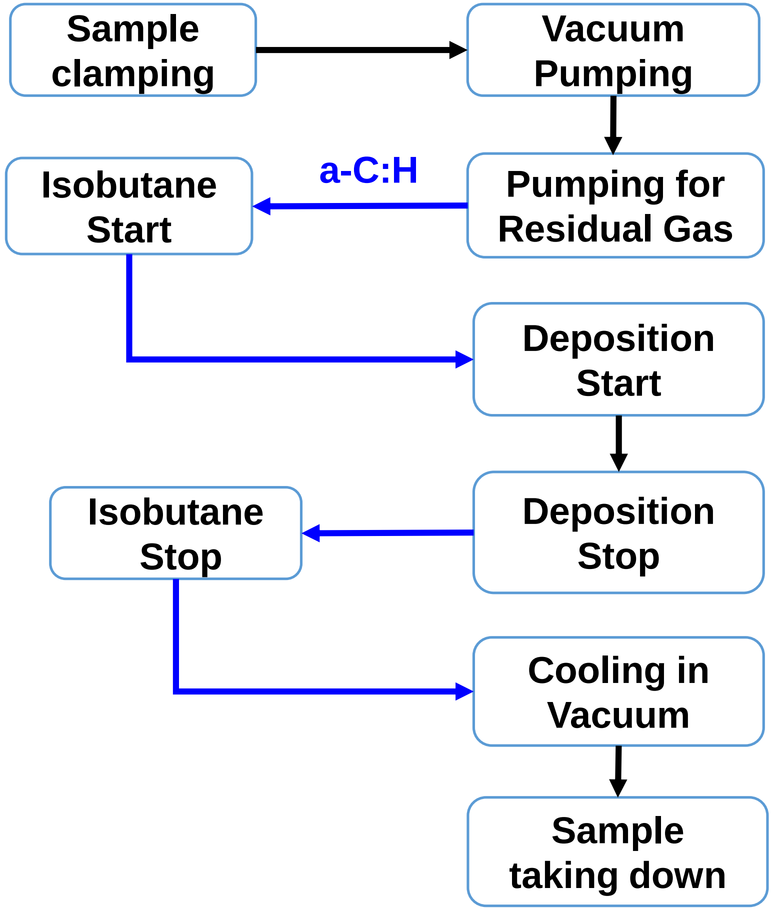
- New type of "DLC+Cu"

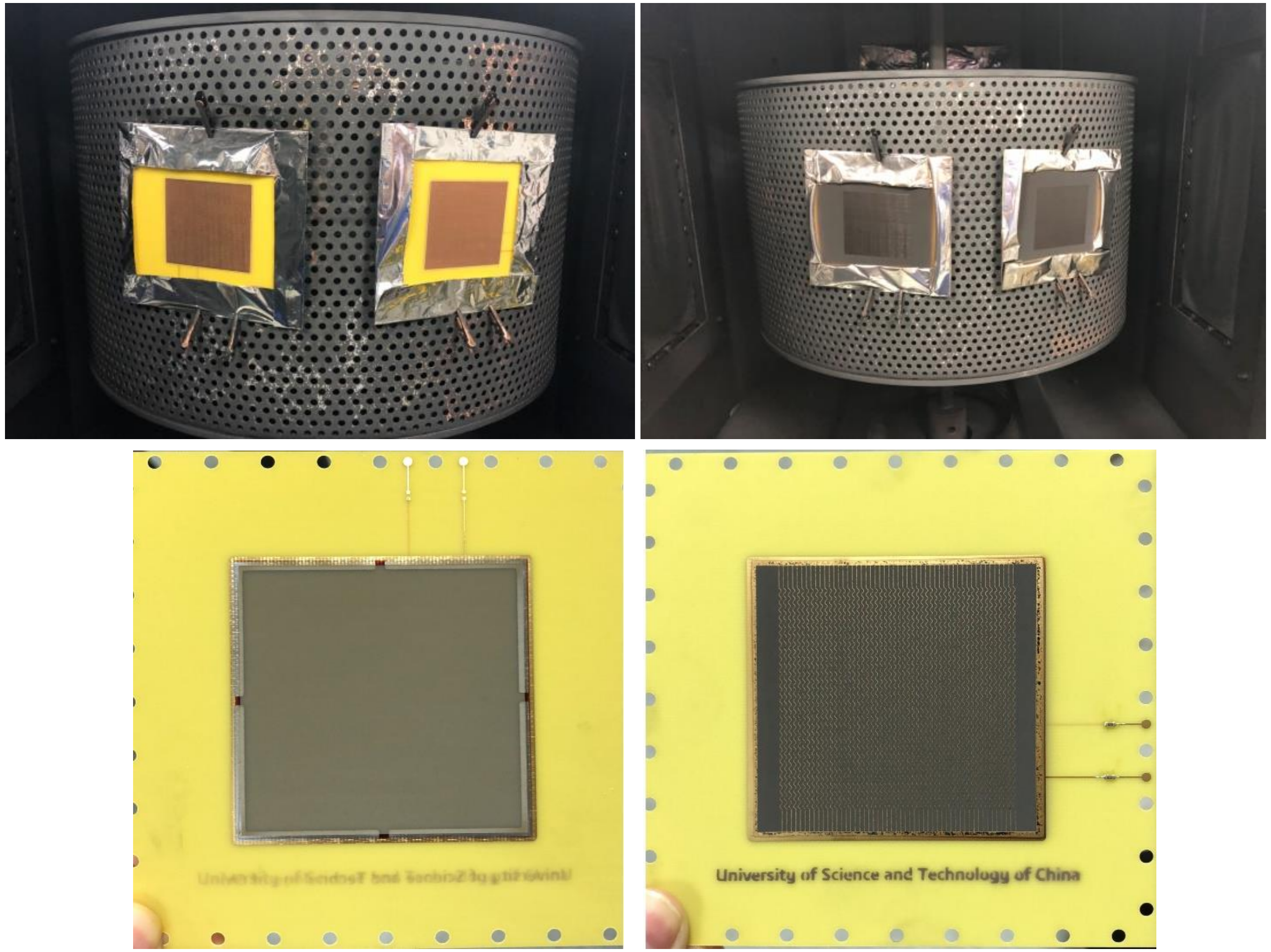
Manufacture precise circuit —(On Apical)→ Control the resistivity → New MPGDs

- DLC as photocathodes

Photoelectric properties —(On MgF_2)→ B-doped, controlling the SP^3 → PICOSEC MicroMegas

Thick DLC on PCB

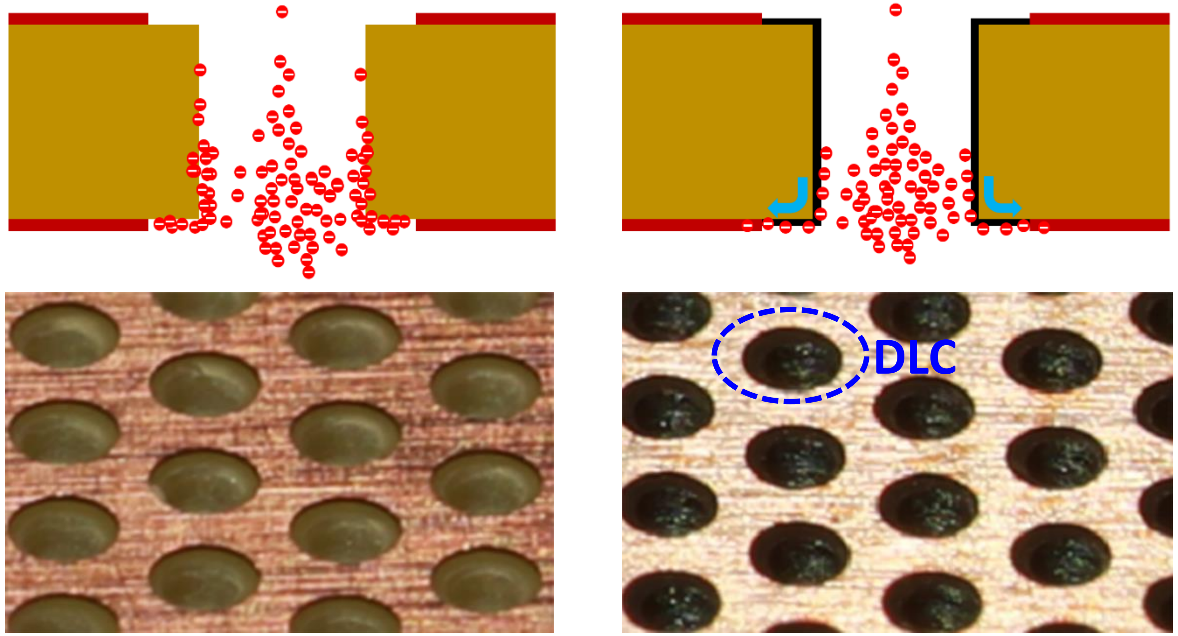


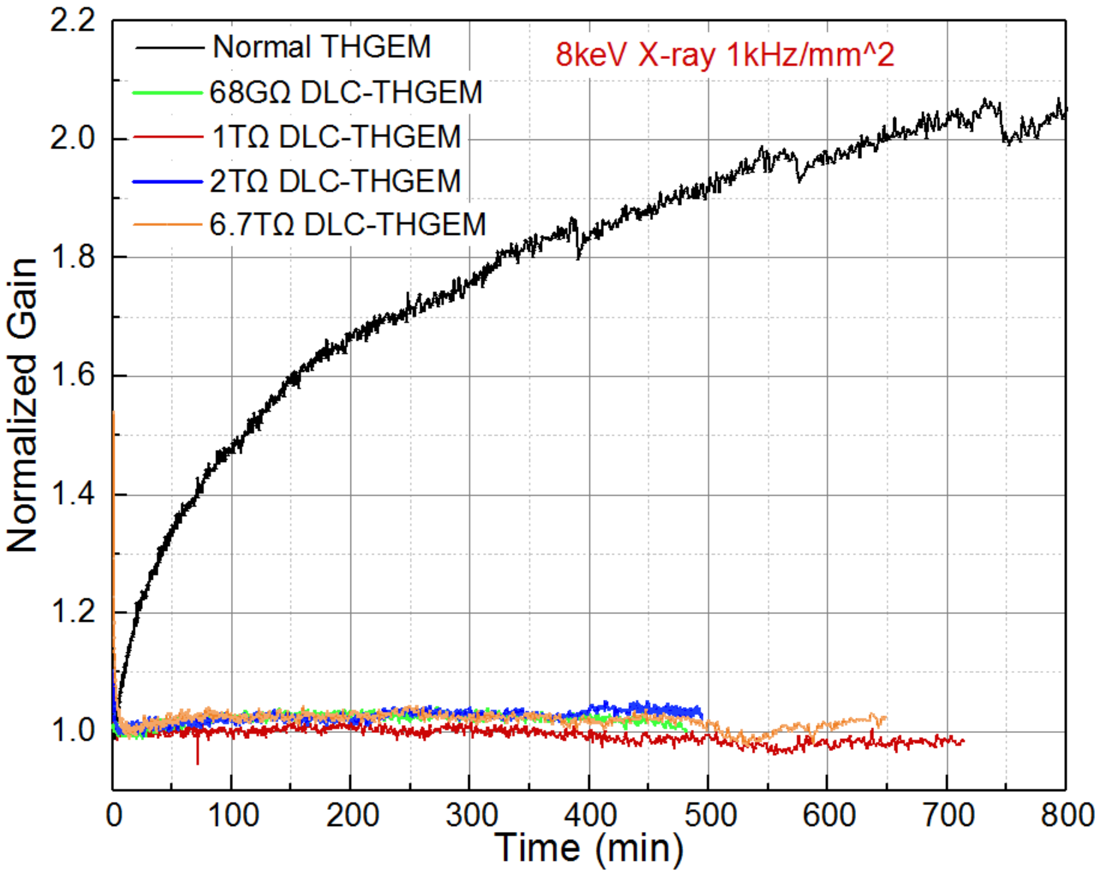


- ✓ ***Allow to make thick DLC (～800nm) which is able to fully cover the surface of FR4;***
- ✓ ***The surface resistivity of DLC can be adjusted from ～kΩ/□ to ～PΩ/□ to fit the requirement of different applications;***

Application 1

Charging up "Free" THGEM





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

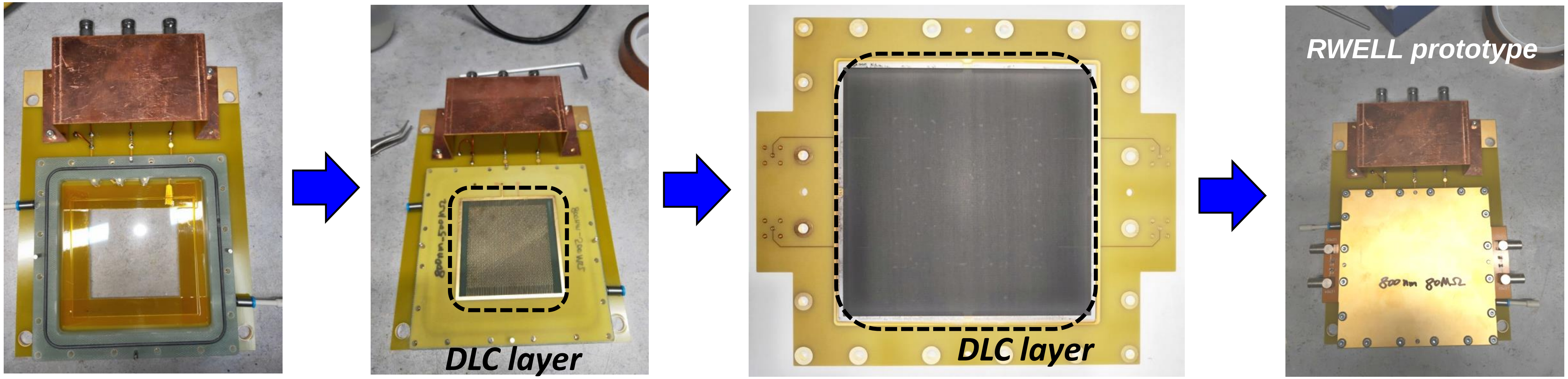
Doping hydrogen by adding isobutane from 7sccm to 9sccm

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

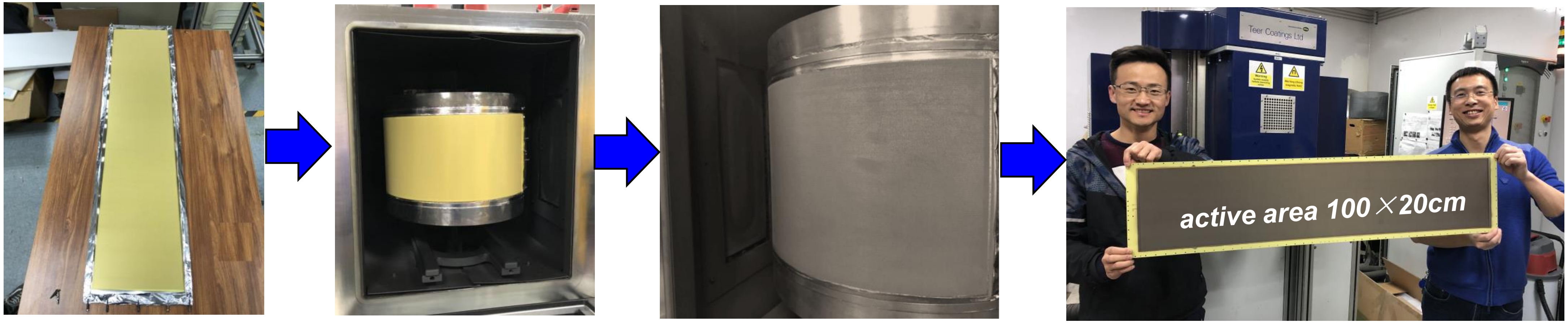
More details in G. Song's talk on this conference

Application 2

Full resistive RWELL



Large scale resistive THGEM



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Cover the rough surface —(On PCB)→ Control the resistivity → THGEM, RPWELL

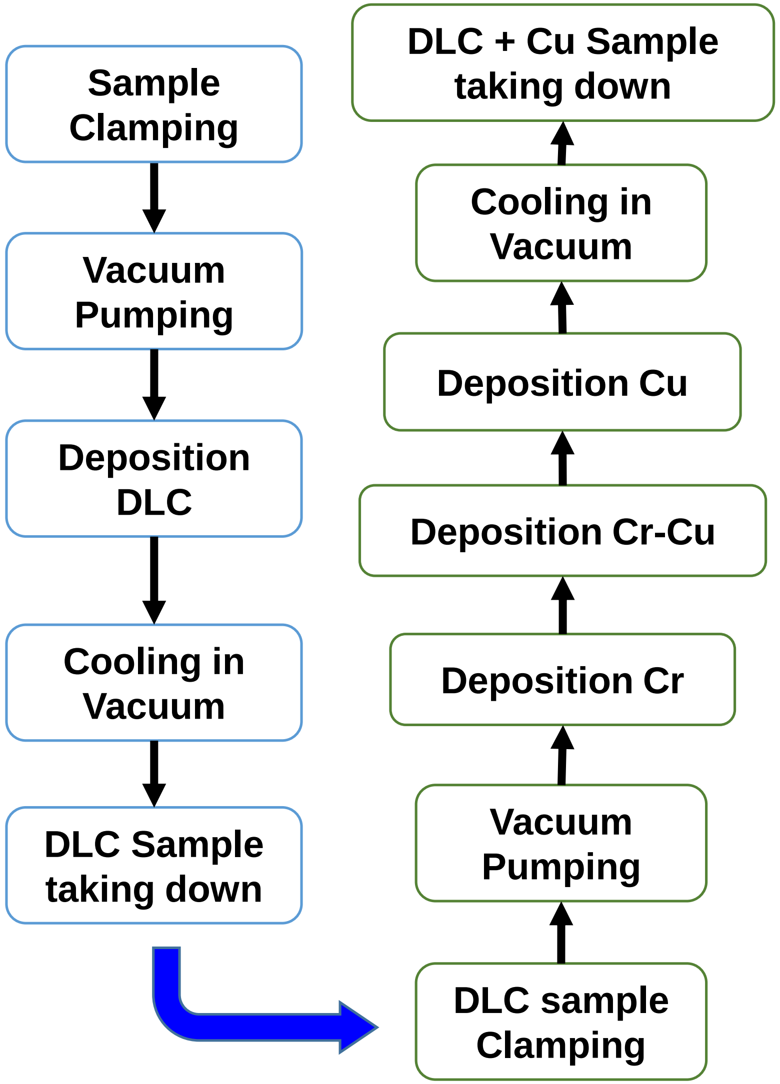
- ***New type of "DLC+Cu"***

Manufacture precise circuit —(On Apical)→ Control the resistivity → New MPGDs

- ***DLC as photocathodes***

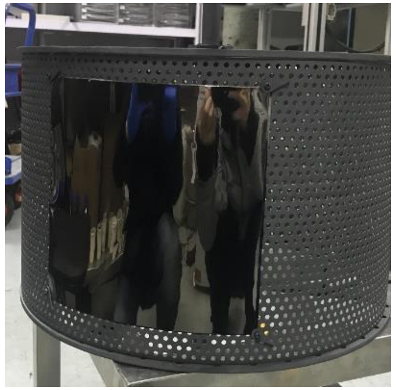
Photoelectric properties —(On MgF_2)→ B-doped, controlling the SP^3 → PICOSEC MicroMegas

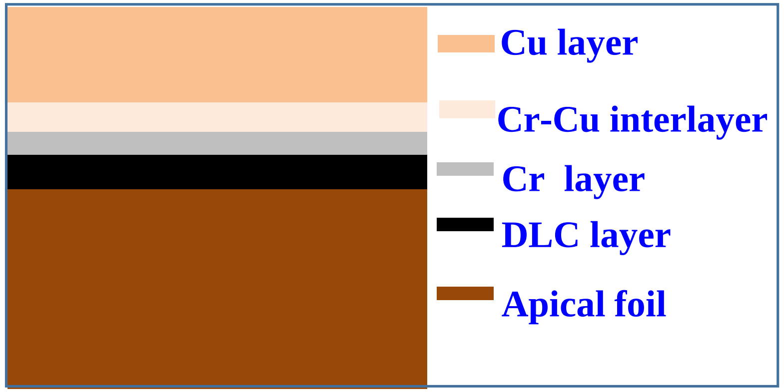
DLC+Cu on APICAL



Advantages of "DLC + Cu"

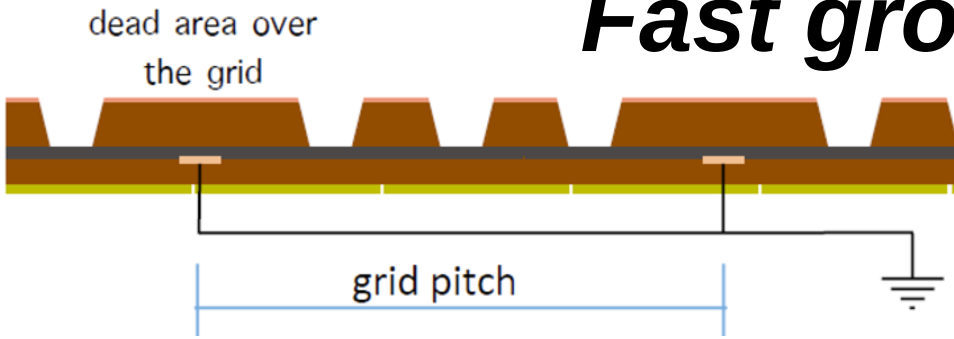
- *Simplifying the manufacture process and improving the quality of resistive MPGDs*
- *Allowing precise printed circuit layouts on DLC resistive electrode thus realizing complex functions*
- *Expanding the capacity and applications of the MPGDs and opening the way for new MPGD architectures*





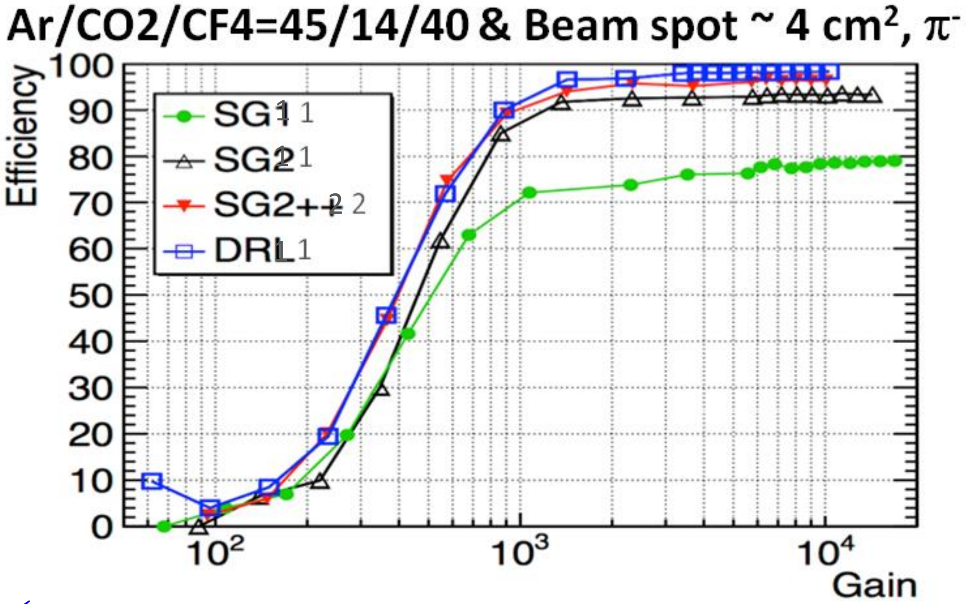
Application

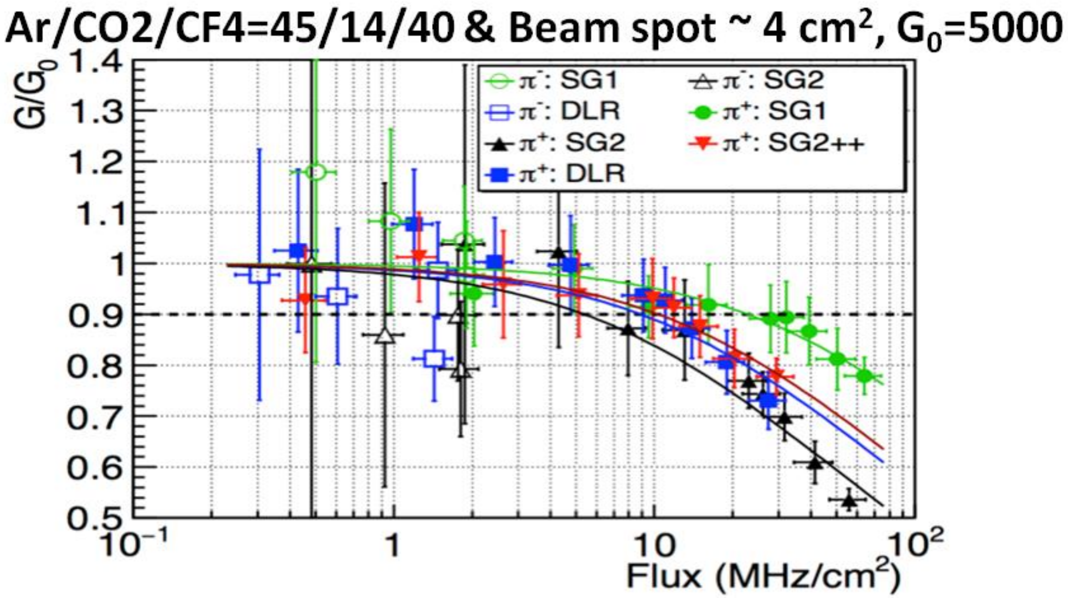
Fast grounding μRWELL



Reduce the dead area

Single DLC-layer with fast grounding copper lines





- ✓ *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

On going projects

- **High-rate applications**

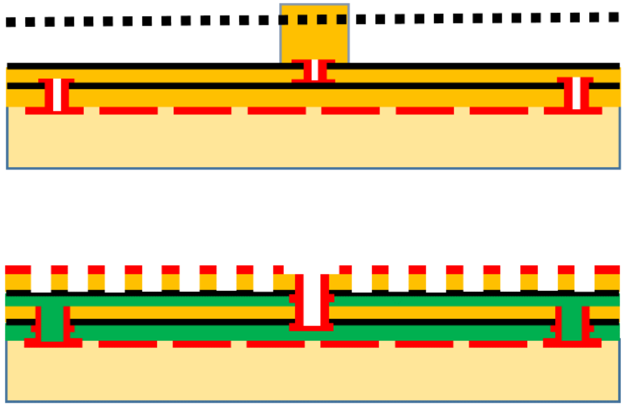
  Double-DLC Micromegas/μRWELL made by Sequential Build Up(SBU) technique

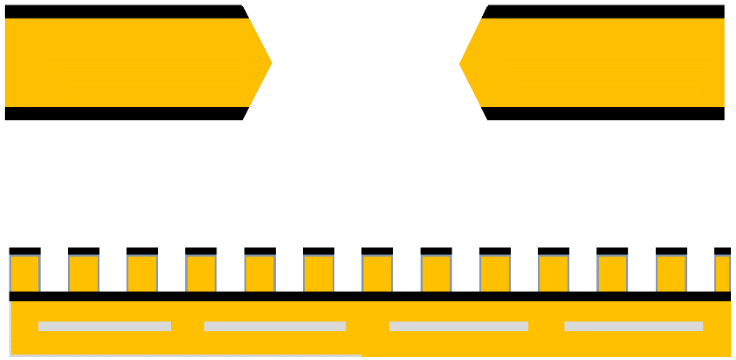
- **Low mass applications**

  Full resistive detectors, like GEM, μRWELL, THGEM, etc...

- **Fast timing applications in high rate environments**

  Fast timing MPGD (FTM)





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- ***DLC as photocathodes***

Photoelectric properties $\xrightarrow{\text{On } MgF_2}$ B-doped, controlling the SP^3 ⟶ PICOSEC MicroMegas

Keys to obtain high QE for photocathode

- ***Improvement of band structure***

  Boron doped DLC by magnetron sputtering deposition

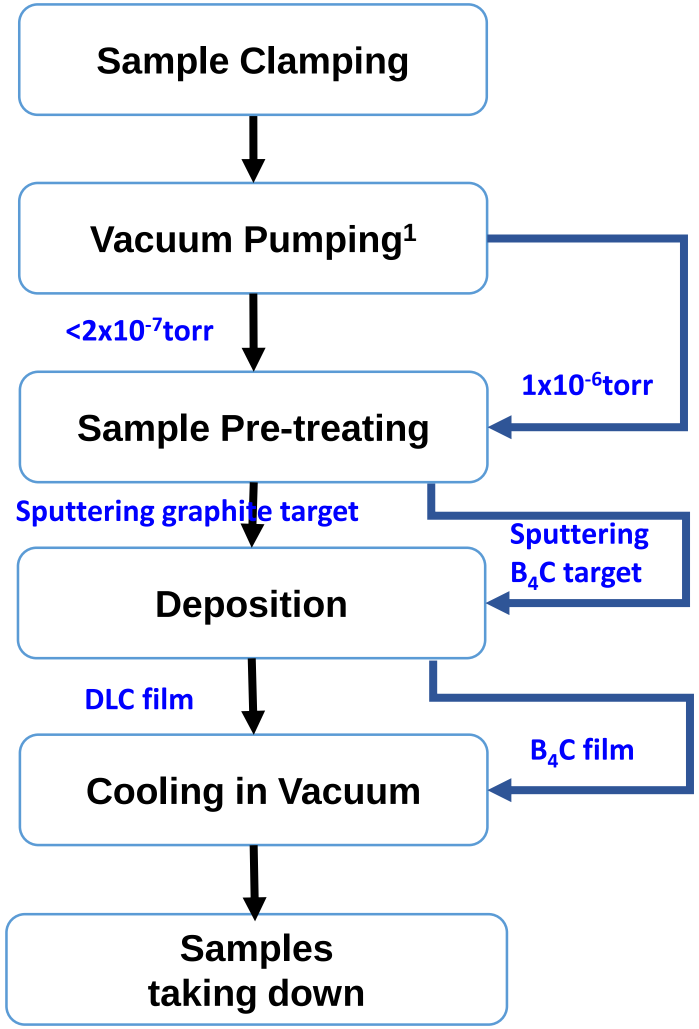
- ***Optimize the ratio of sp^3/sp^2 of DLC***

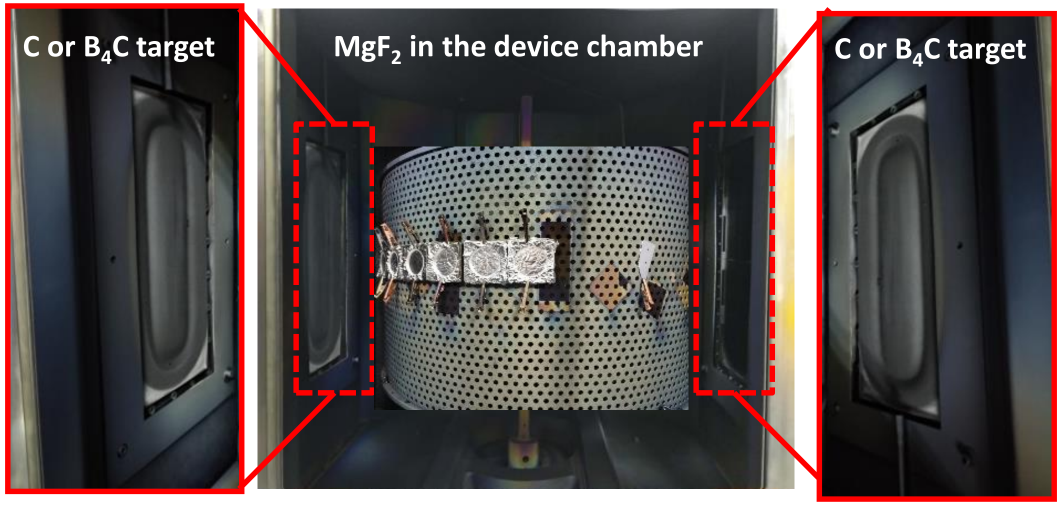
  Increasing the content of sp^3 by vacuum cathodic arc & pulsed laser deposition

- ***Reducing the surface electron affinity***

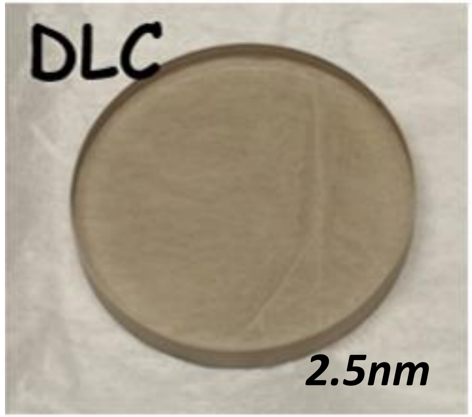
  Surface treatment, hydrogenation of the DLC surface by MWPECVD technique

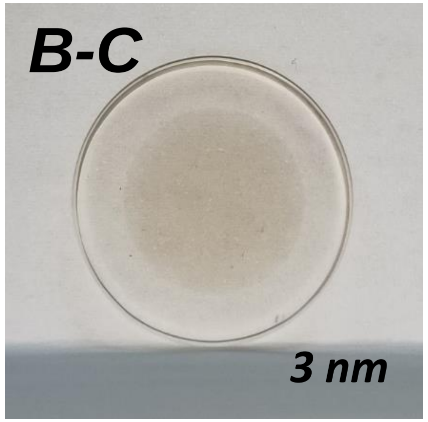
Deposition of pure DLC & B-C photocathode





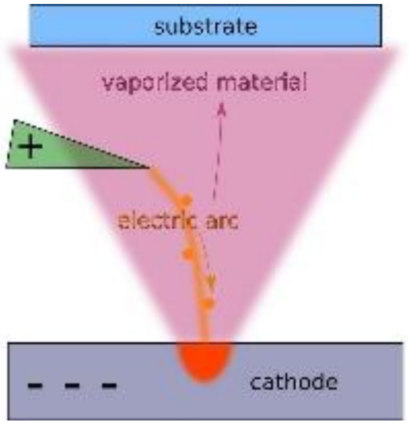
Preparation pure DLC and B-C film on photocathode by MS deposition





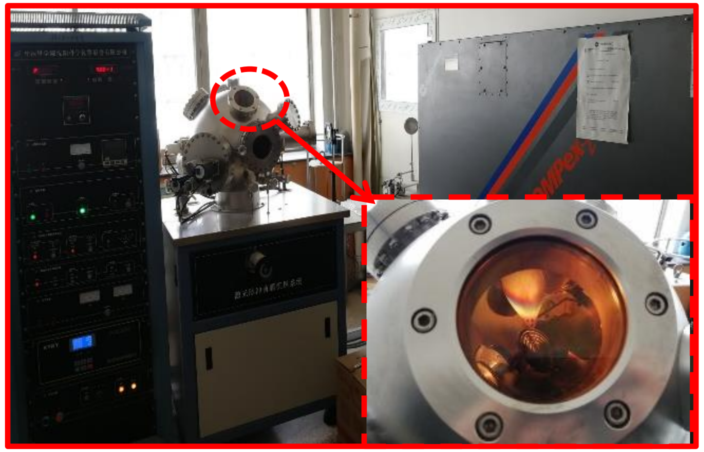
1. Achieve specific vacuum degree by controlling the pumping time

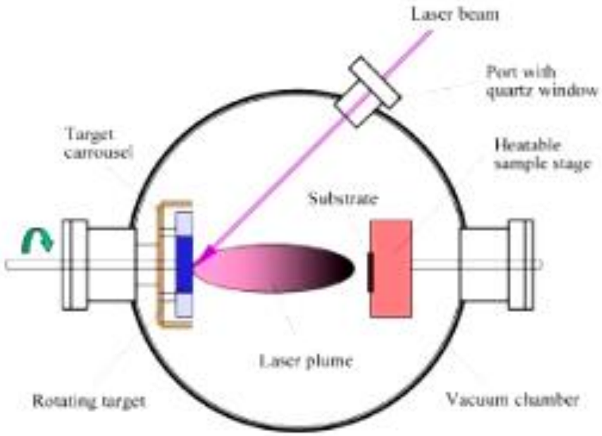
Deposition of ta-C photocathode



Sample Clamping
↓
Vacuum Pumping
↓
Injecting Argon
↓
Arc discharge
↓
Deposition
↓
Samples taking down

Vacuum Cathodic arc deposition (VCAD)

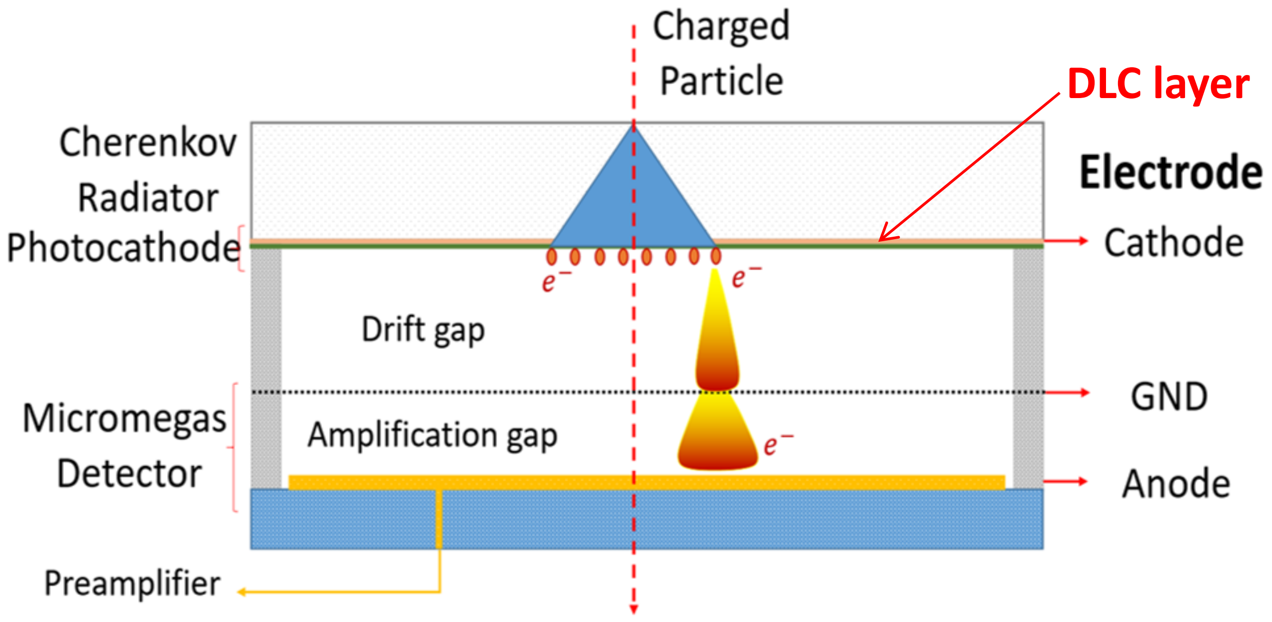




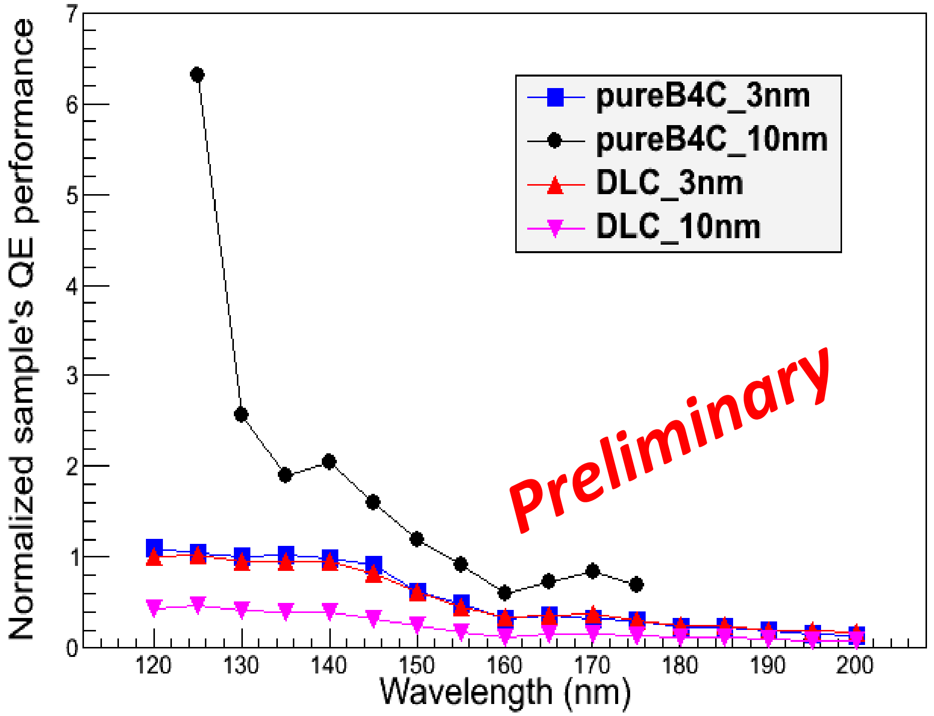
Sample Clamping
↓
Vacuum Pumping
↓
Pulsed laser
↓
High temperature ablation
↓
Deposition
↓
Samples taking down

Pulsed laser deposition (PLD)

Application on PICOSEC MicroMegas detector



PICOSEC detector concept



The results of Normalized QE vs wavelength

Achieve good results applied on PICOSEC MicroMegas detector

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 MgF_2 for photocathode.**

◆ **Development of DLC resistive electrodes opens up enormous opportunities for innovative development and application of MPGDs.**

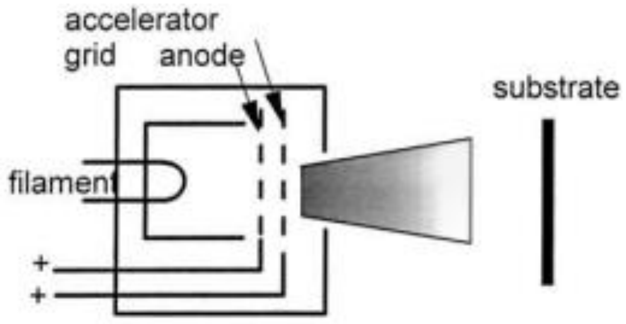
Outlook:

◆ **Developing the deposition of large area (> 40 cm × 100 cm) resistive DLC electrode**

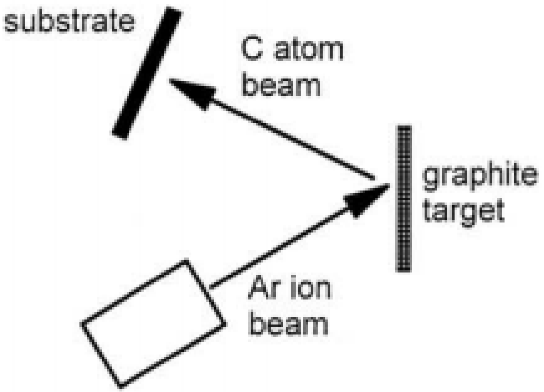
◆ **Developing more MPGDs with new structure, such as fast grounding μRWELL， Full resistive μRWELL， Full resistive GEM， and so on.**

Thank You

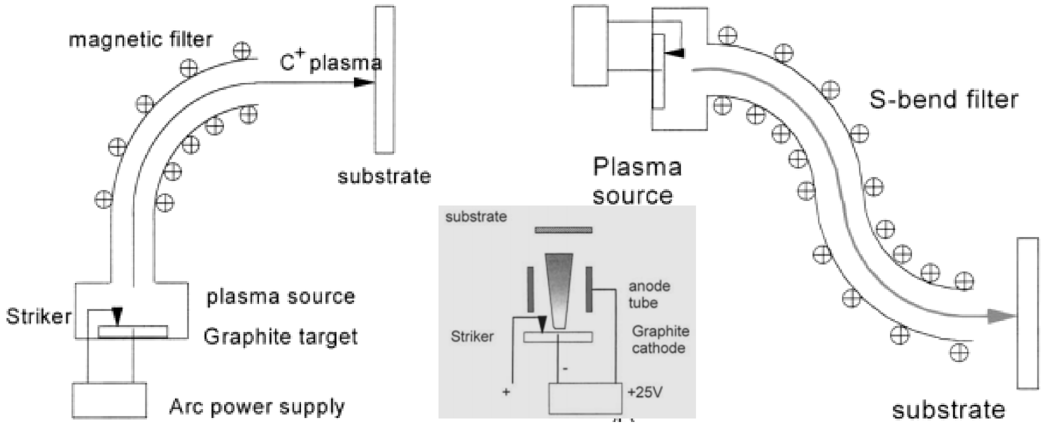
Back up



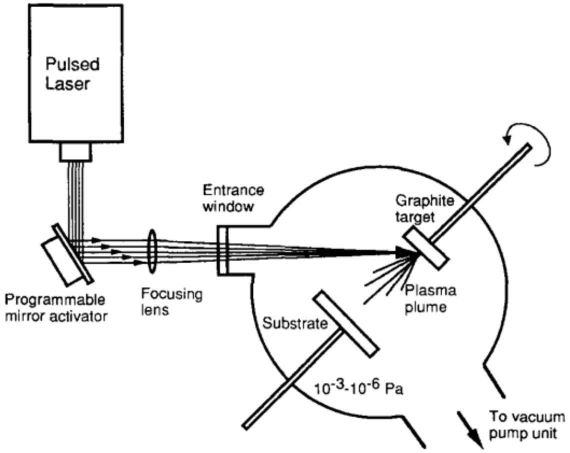
Ion deposition



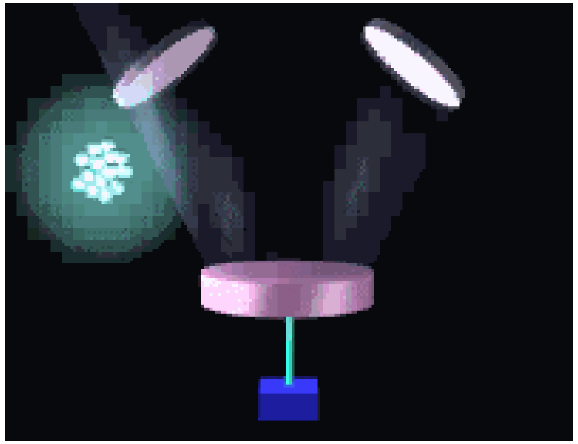
Ion assisted deposition



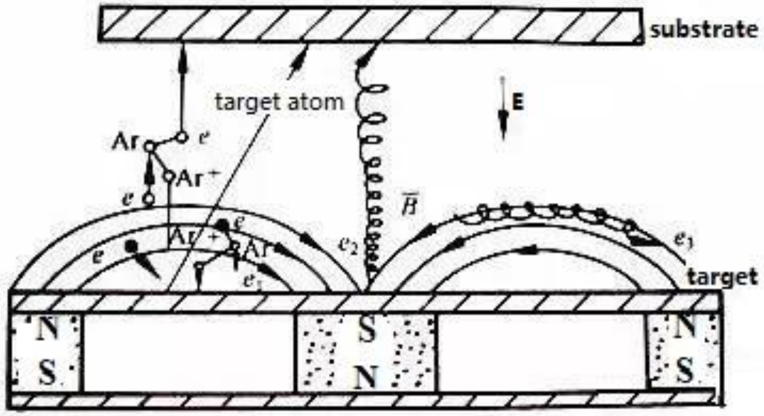
Filtered cathodic vacuum arc deposition



Pulsed laser deposition

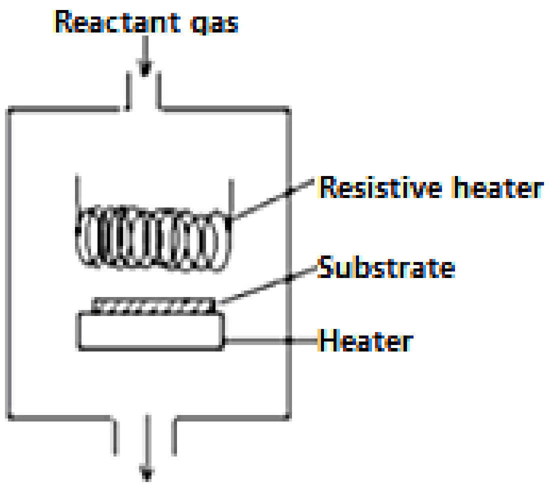


Dynamic diagram of sputtering deposition

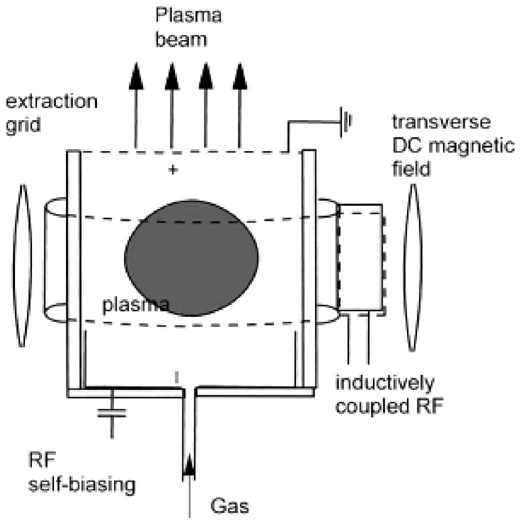


Magnetron sputtering deposition

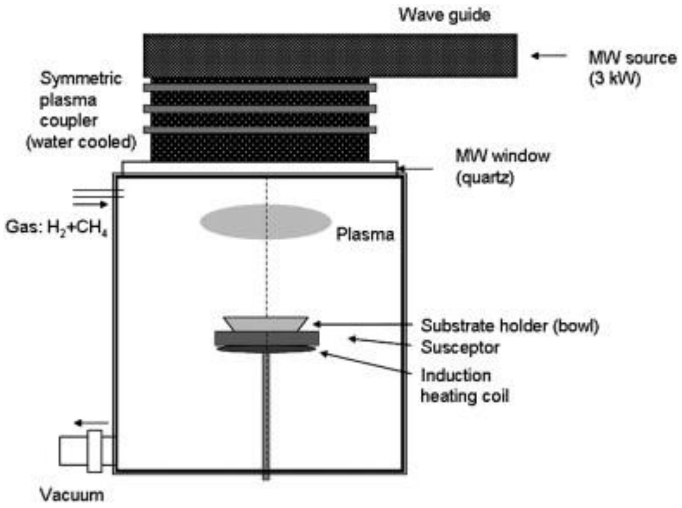
- ***Low deposition temperature (<300℃);***
- ***High bonding strength and low internal stress***



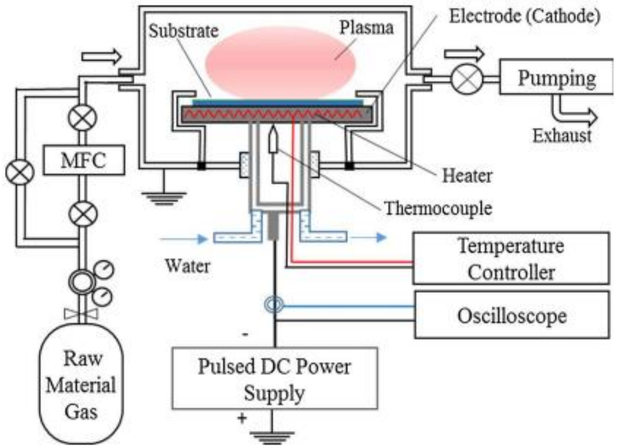
Hot wire CVD



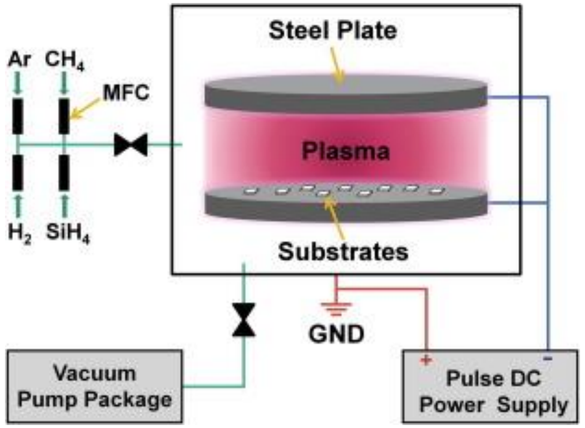
Electron cyclotron resonance CVD



Microwave plasma CVD

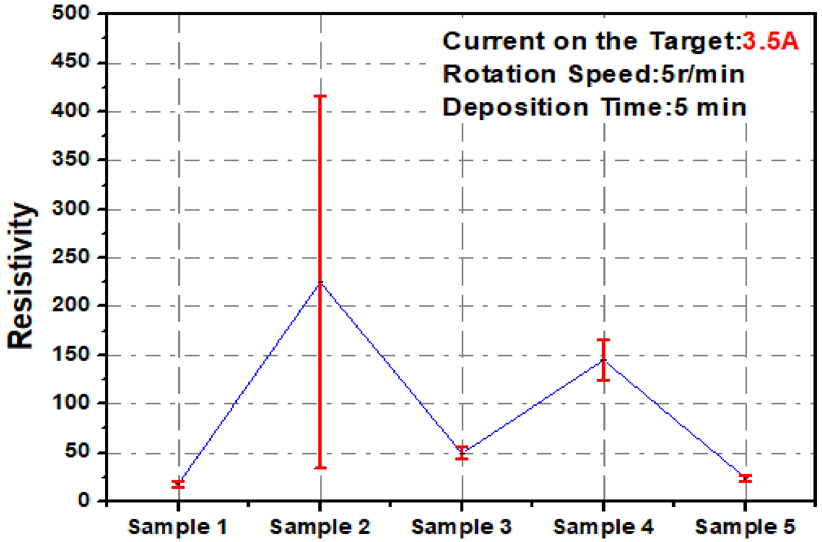


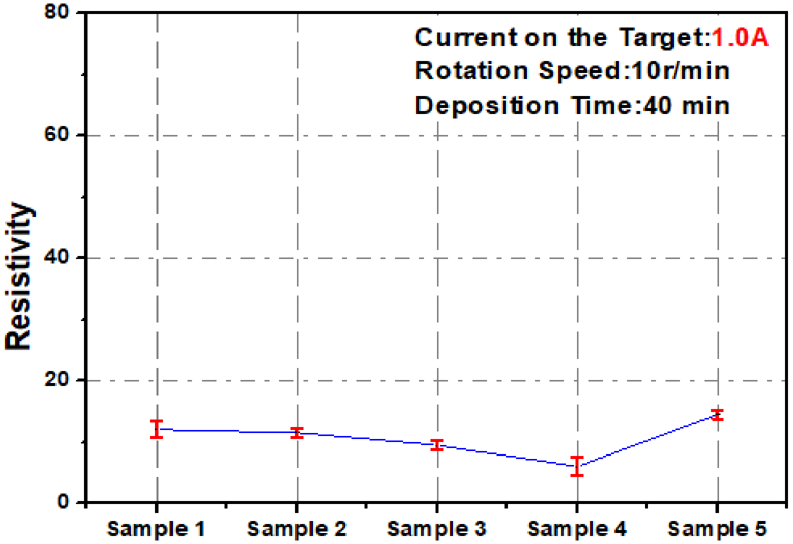
Pulsed DC plasma CVD

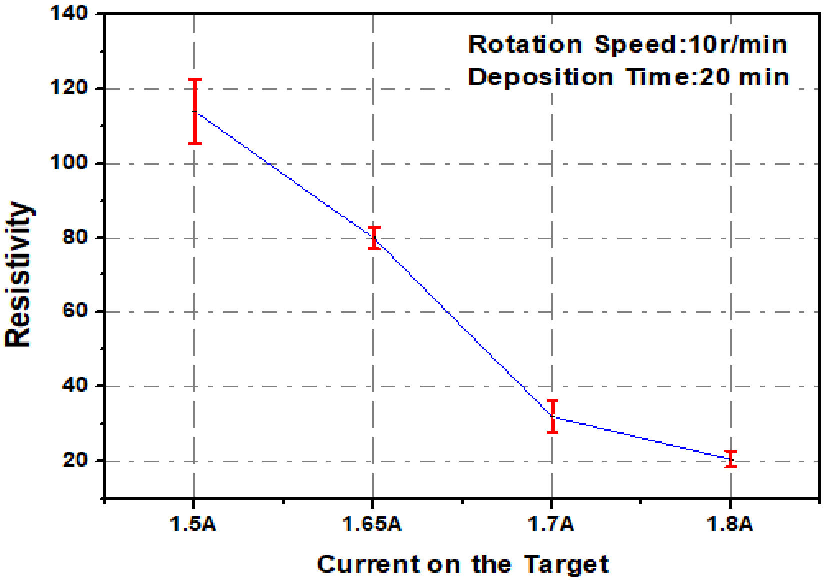


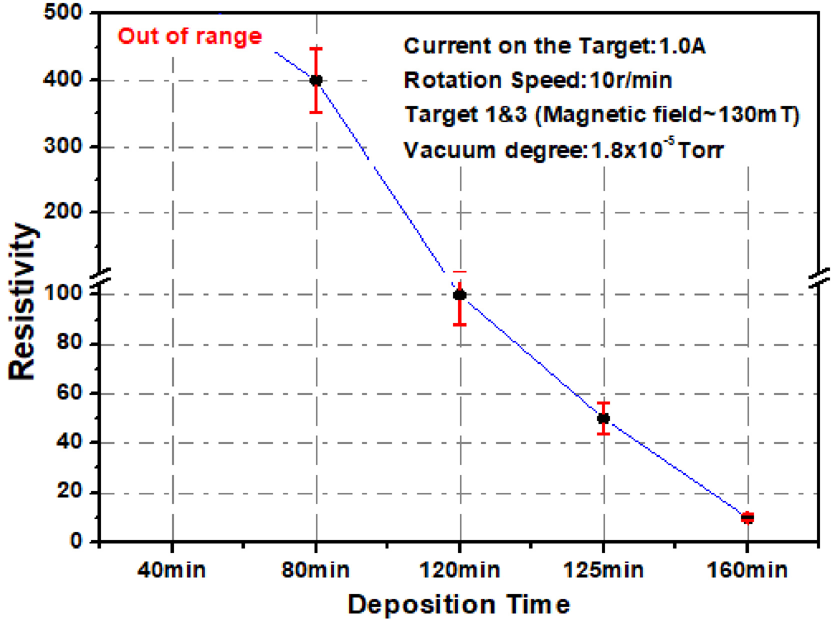
Plasma enhanced CVD

- ***Dissociation of hydrocarbon gas***
- ***No graphite targets***
- ***High deposition temperature(>300℃)***
- ***High deposition rate***
- ***More sp^3 structures***

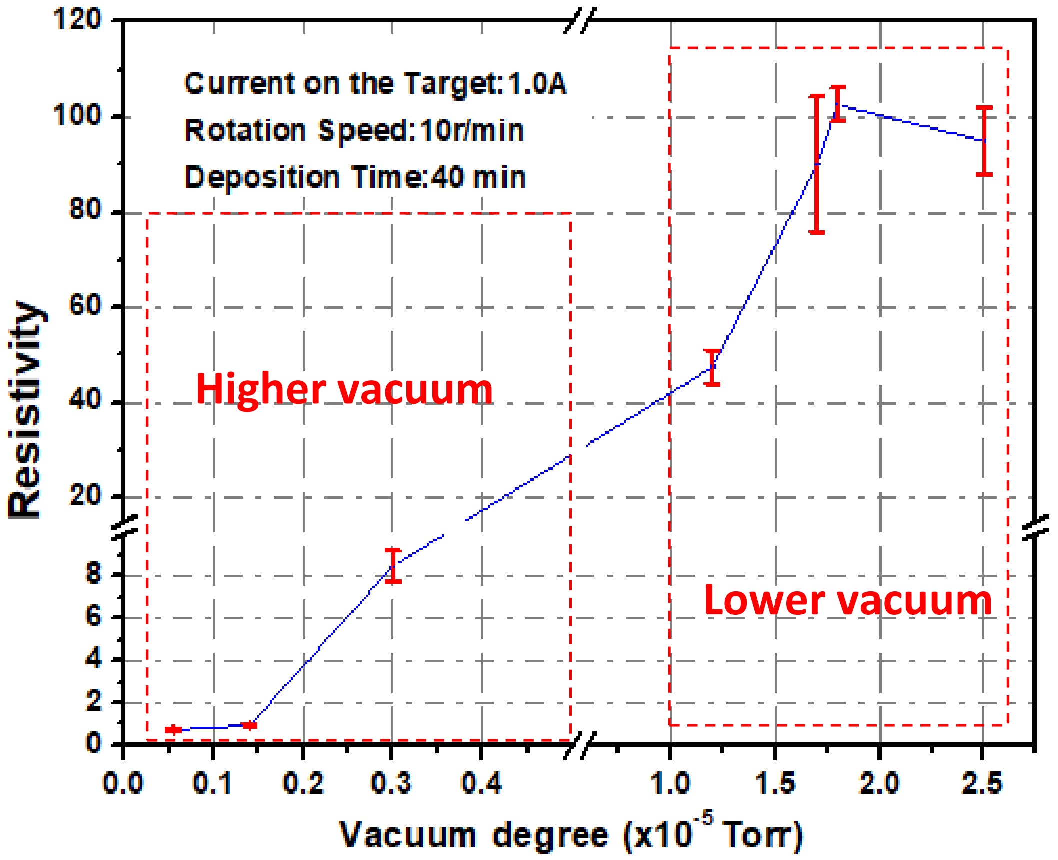


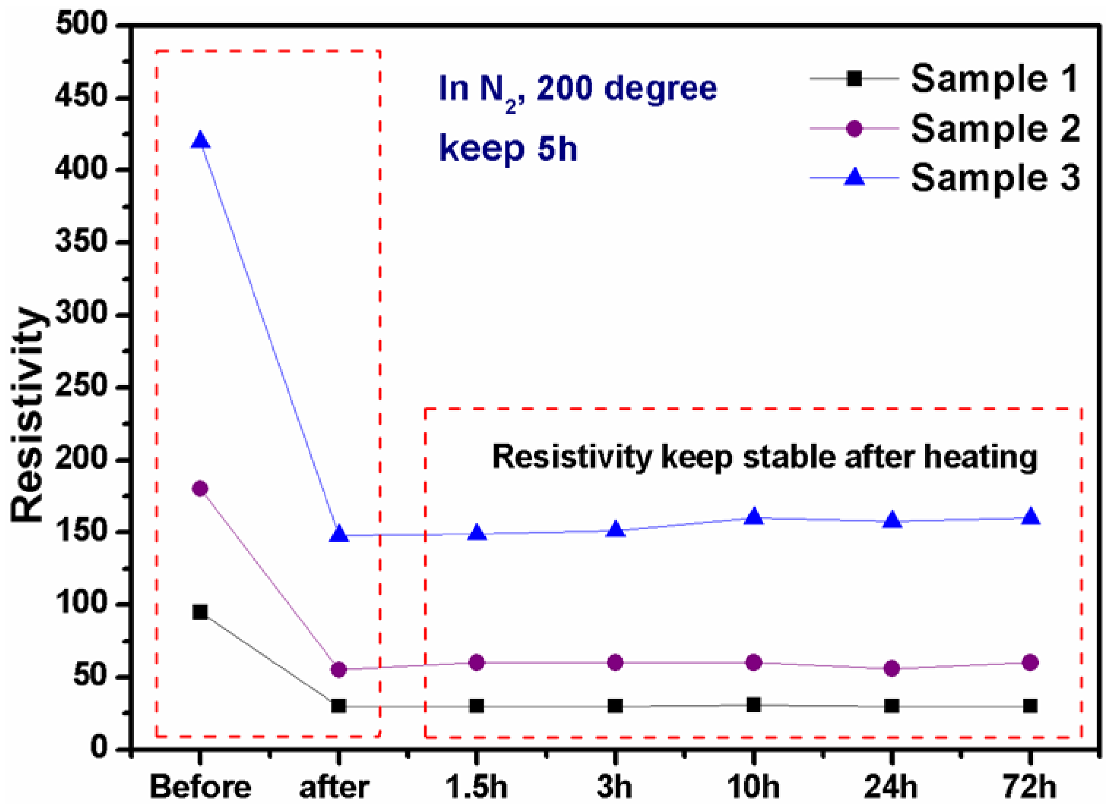




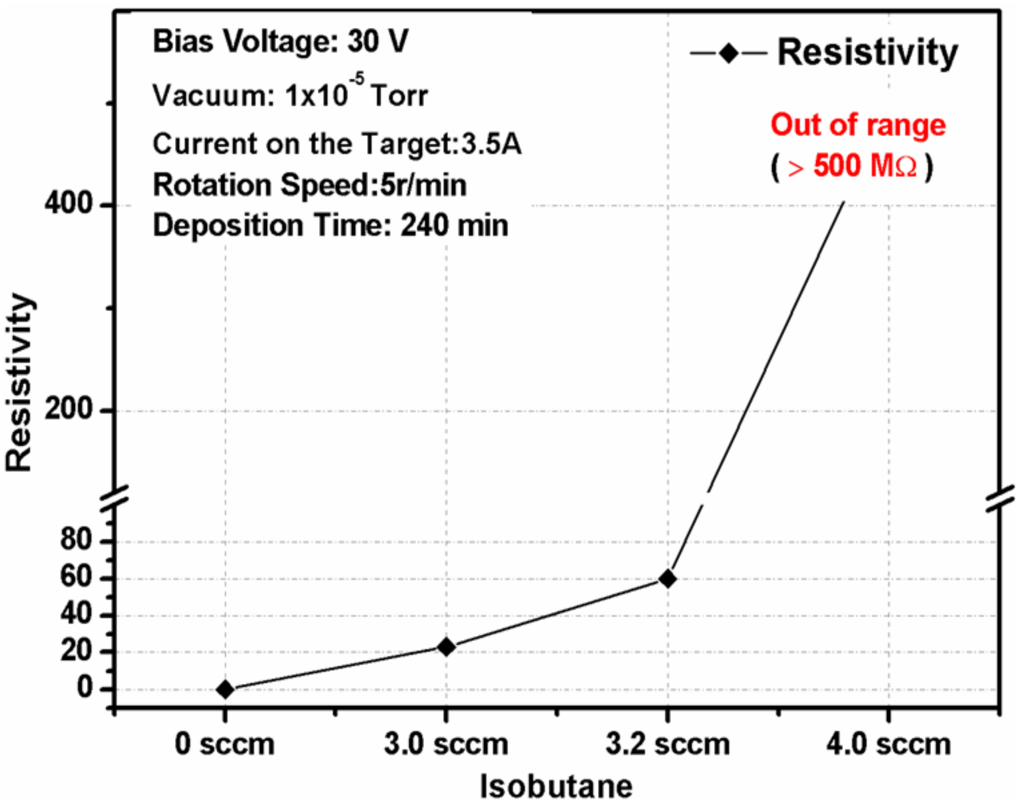


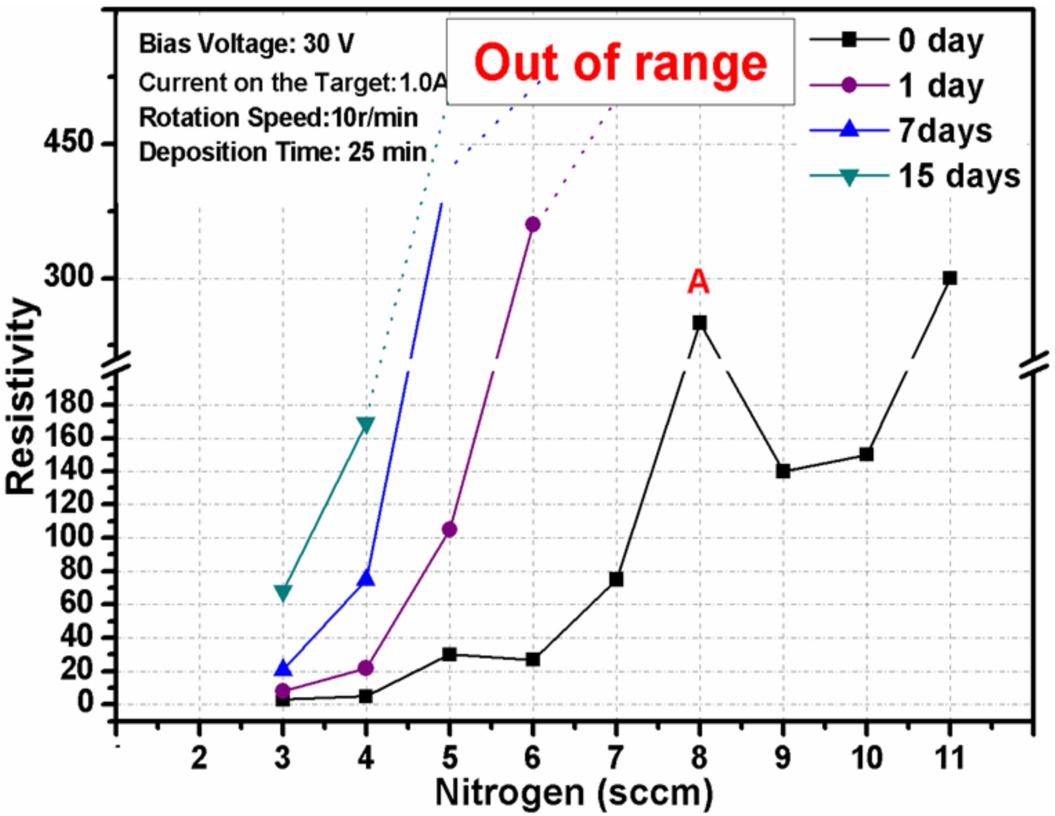
- ***The resistance is greatly affected by the target current***
- ***The smaller target current, the more uniform resistivity***
- ***The resistivity tends to decrease with the increase of the target current and deposition time***
- ***The greater thickness of the DLC, the smaller resistivity***





- ***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