# Common project: Development of Prepreg with Controllable Resistivity

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**DRD1 collaboration meeting, Warsaw - 10/10/25**

# State of the art

# Resistive electrodes for gaseous detectors

Gaseous detectors require planar electrodes with

- Resistive material facing gas
  → small electrical conductivity in the ESD or antistatic range to quench energy of gas breakdown (discharges)
- PCB substrate with conductive pads
  → normal electrical conductivity to read out induced signals

**Planar electrode**

**Substrate PCB**

A. Capacitive coupling: Copper + insulator

B. Direct coupling: Copper

\+

**Resistive material**

A. Resistive layer
   - Thin layer of film
   - surface resistivity $100\ \mathrm{k}\Omega/\square$ - $\mathrm{G}\Omega/\square$

B. Resistive plate
   - o(mm) thick
   - Bulk resistivity $10^9 - 10^{11}\ \Omega \cdot \mathrm{cm}$

# Resistive layers

**Insulator substrate**

- Polyimide, FR4
    - Contributing to surface quality

**Coatings**

- **Graphite + Lacquer**
    - Spray
    - Cheap
    - Limited control on resistivity
    - Prone to defects and aging
- **Screen printed ink**
    - Good control on resistivity
    - Difficult to scale up
- **Diamond like carbon (DLC)**
    - DC magnetron vacuum deposition
    - Good control on resistivity
    - Resistant to aging
    - Costly machine and difficult to scale up

Planar electrode

Substrate PCB

A. Capacitive coupling: Copper + insulator

+

Resistive material

A. Resistive layer
- Thin layer of film
- surface resistivity $100\ \mathrm{k}\Omega/\square$ - $\mathrm{G}\Omega/\square$

| Detectors | Resistive layer |
|---|---|
| **Thin Gap Chamber (TGC)** | • Graphite+Lacquer<br>• DLC |
| **RWELL** | • Graphite+Lacquer<br>• DLC |
| **MicroMegas** | • Screen printed ink<br>• DLC |
| **Micro RWELL** | • DLC |

# Resistive Plates

- **Bakelite (HPL)**
  - Cheap
  - Rough surface quality
  - Fixed high resistivity
- **Glass**
  - Smooth surface quality
  - Fixed high resistivity
  - No industrial PCB integration
- **Doped glass**
  - Fixed lower resistivity
  - Limited availability
- **Plastic materials**
  - Rough surface quality
  - Different resistivity values (mostly fixed)
  - Thick plates
  - No industrial PCB integration
  - Prone to aging

Planar electrode

Substrate PCB

A. Capacitive coupling: Copper + insulator

B. Direct coupling: Copper

+

Resistive material

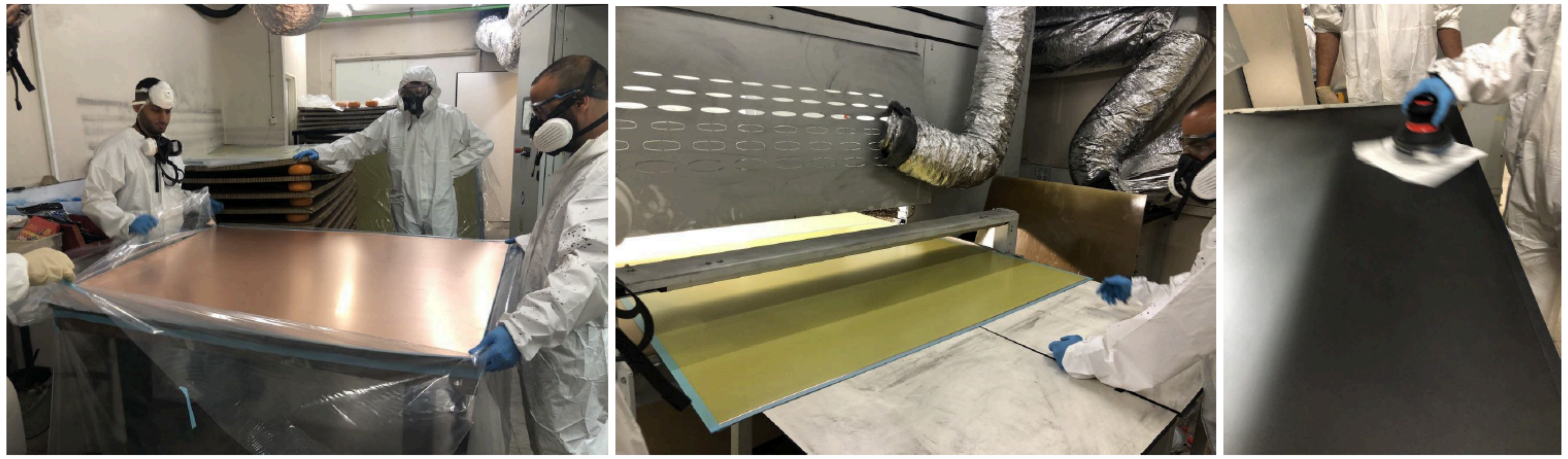
B. Resistive plate
- o(mm) thick
- Bulk resistivity $10^9 - 10^{11}\ \Omega \cdot \mathrm{cm}$

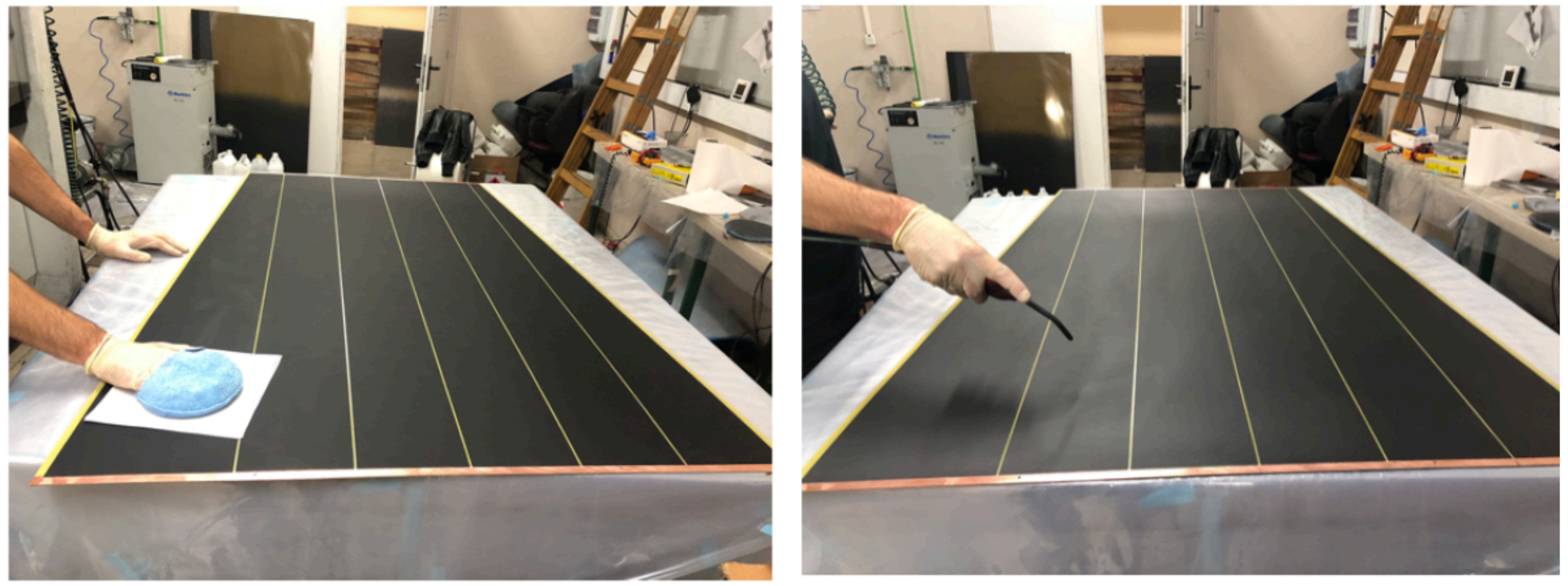
| Detectors | Resistive layer | Coupling |
|---|---|---|
| **Resistive Plate Chambers (RPC)** | • Bakelite<br>• Glass<br>• Doped glass | Capacitive |
| **RPWELL** | • Doped glass<br>• Plastic materials | Direct |

# Resistive layers

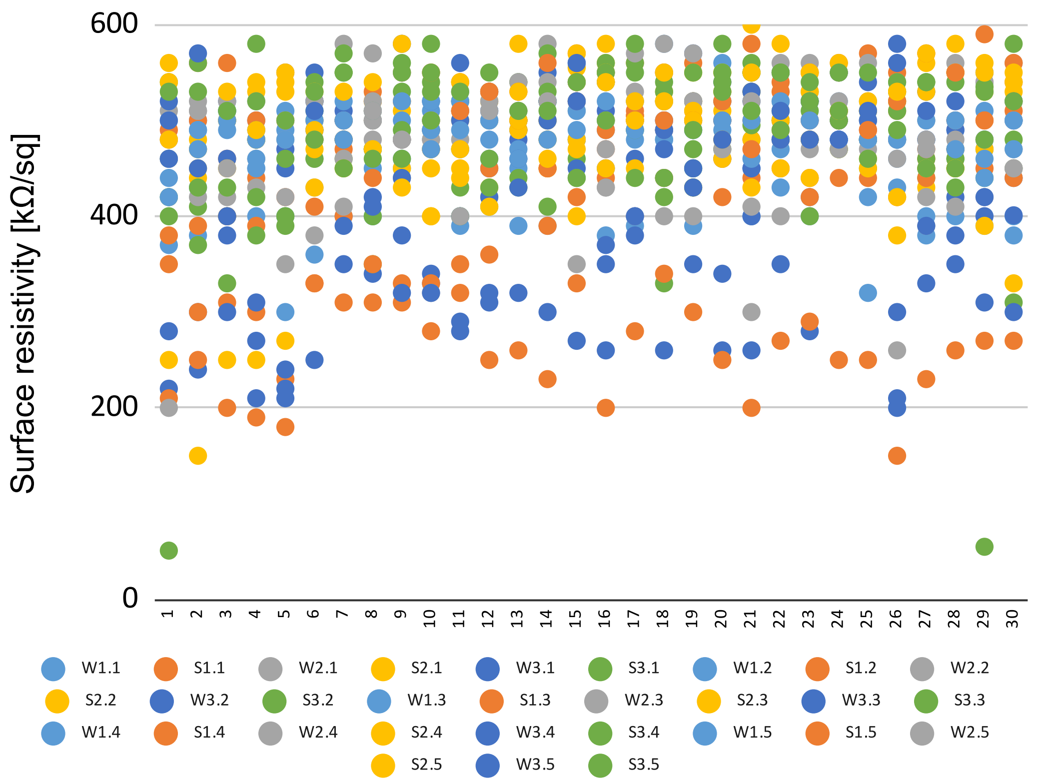
## Graphite + Lacquer on FR4

### TGC Cathode board spraying with graphite + Lacquer





### Graphite resistivity




Advantages

- Resistivity controlled by
  - spraying speed
  - graphite concentration

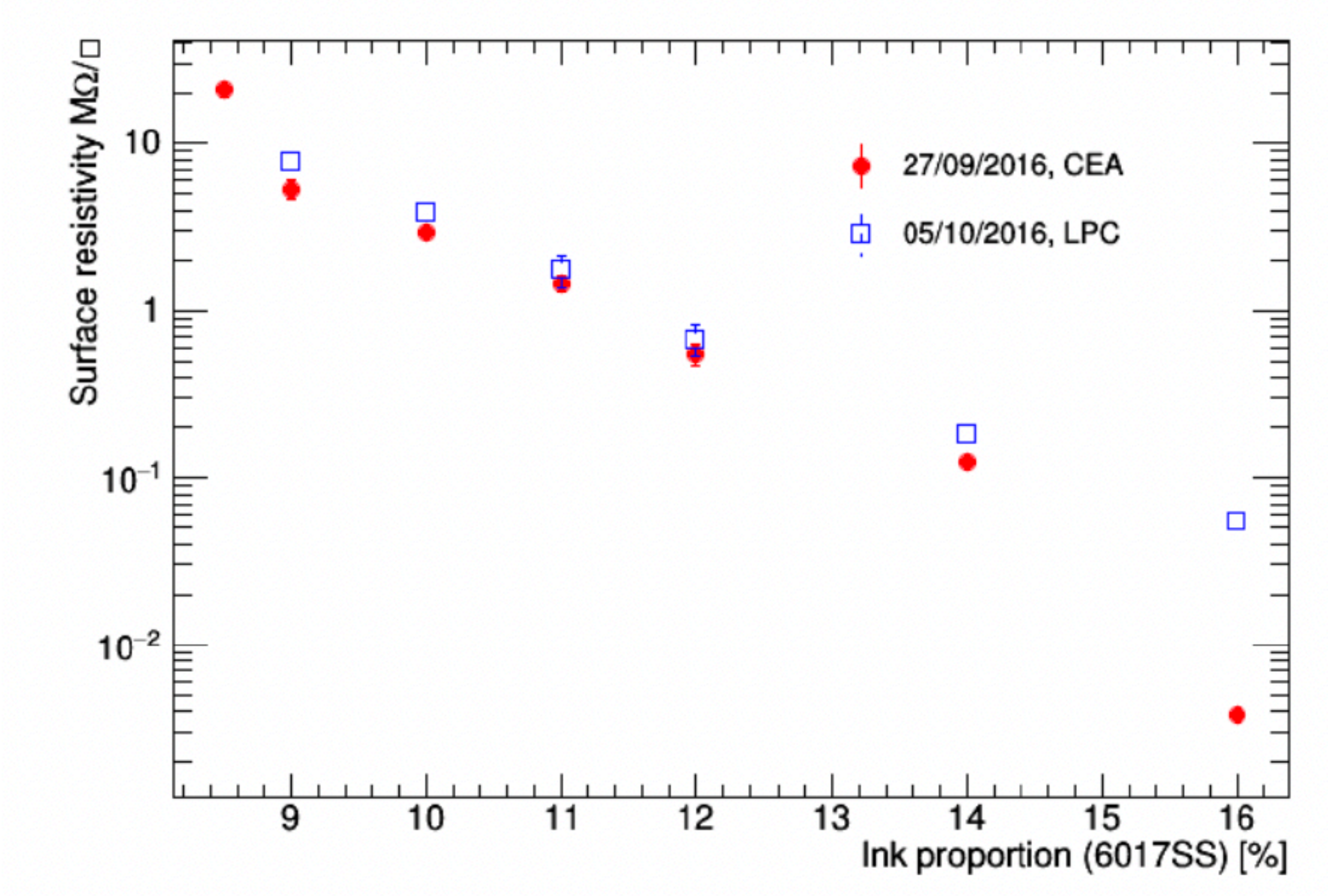
Limitations

- Dirty process
- Resistivity sensitive to humidity and temperature
- Delicate layer
  (degradable by hydrocarbon solvents and electric discharges)
- Rough surface

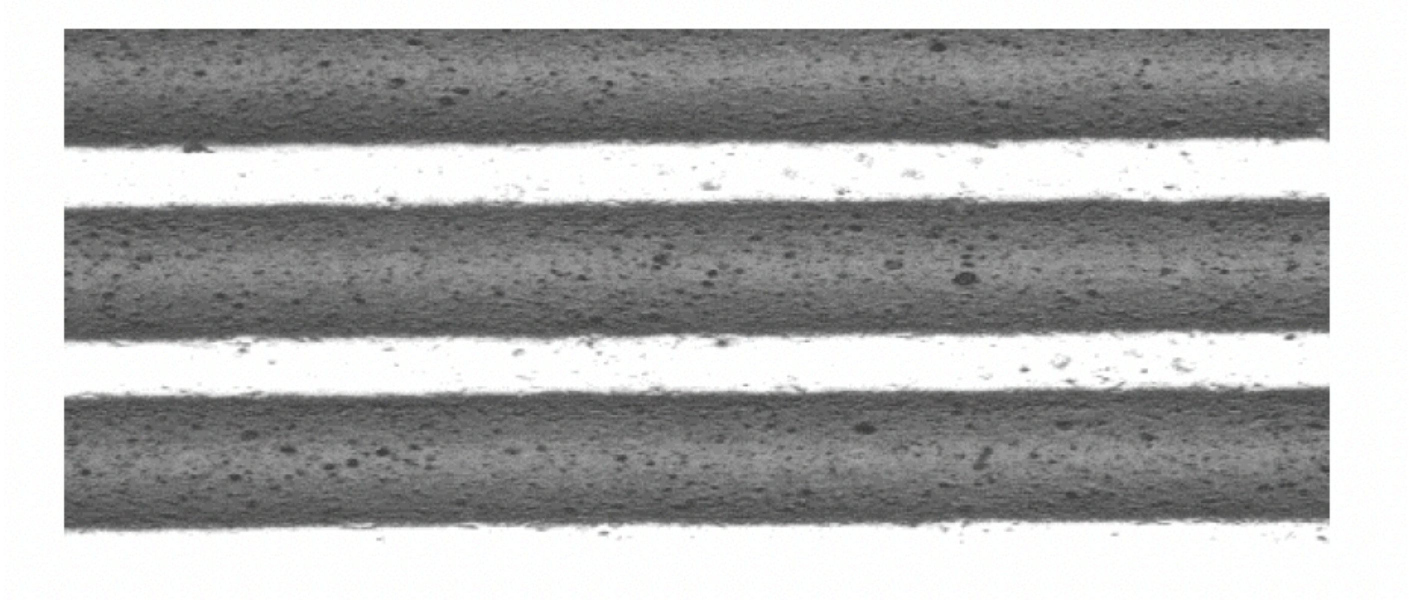
# Resistive layers

## Screen printing ink on Polyimide

**Resistivity tuning**

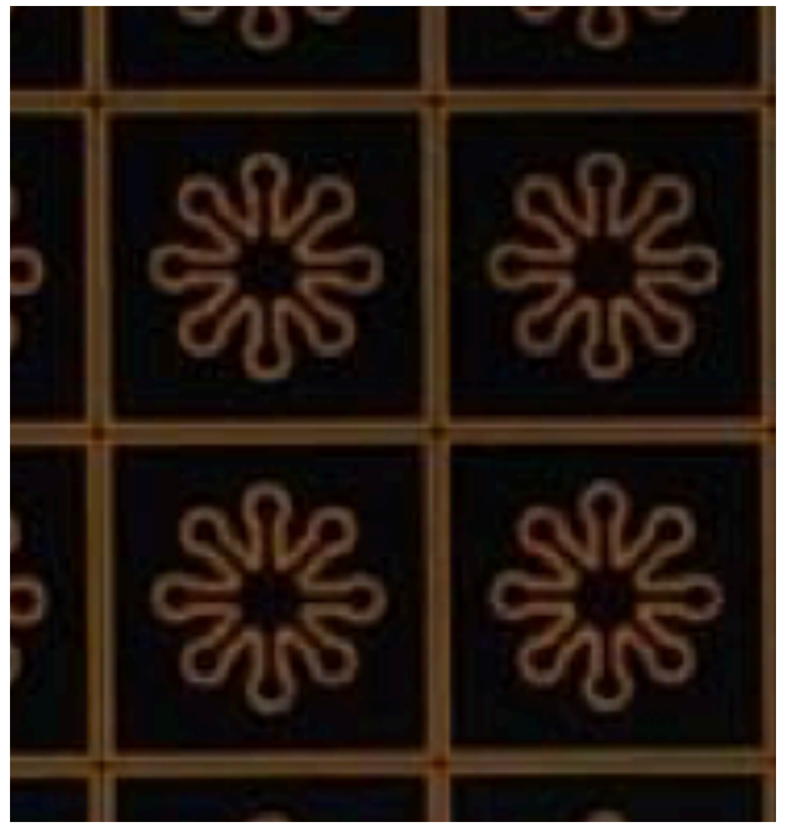



**Strip pattern of resistive ink**



480 μm pitch

**Custom pattern of resistive ink pads**



Advantages

- Good control on resistivity by ink content
- Standard technology implemented in PCB processes
- Easy to pattern

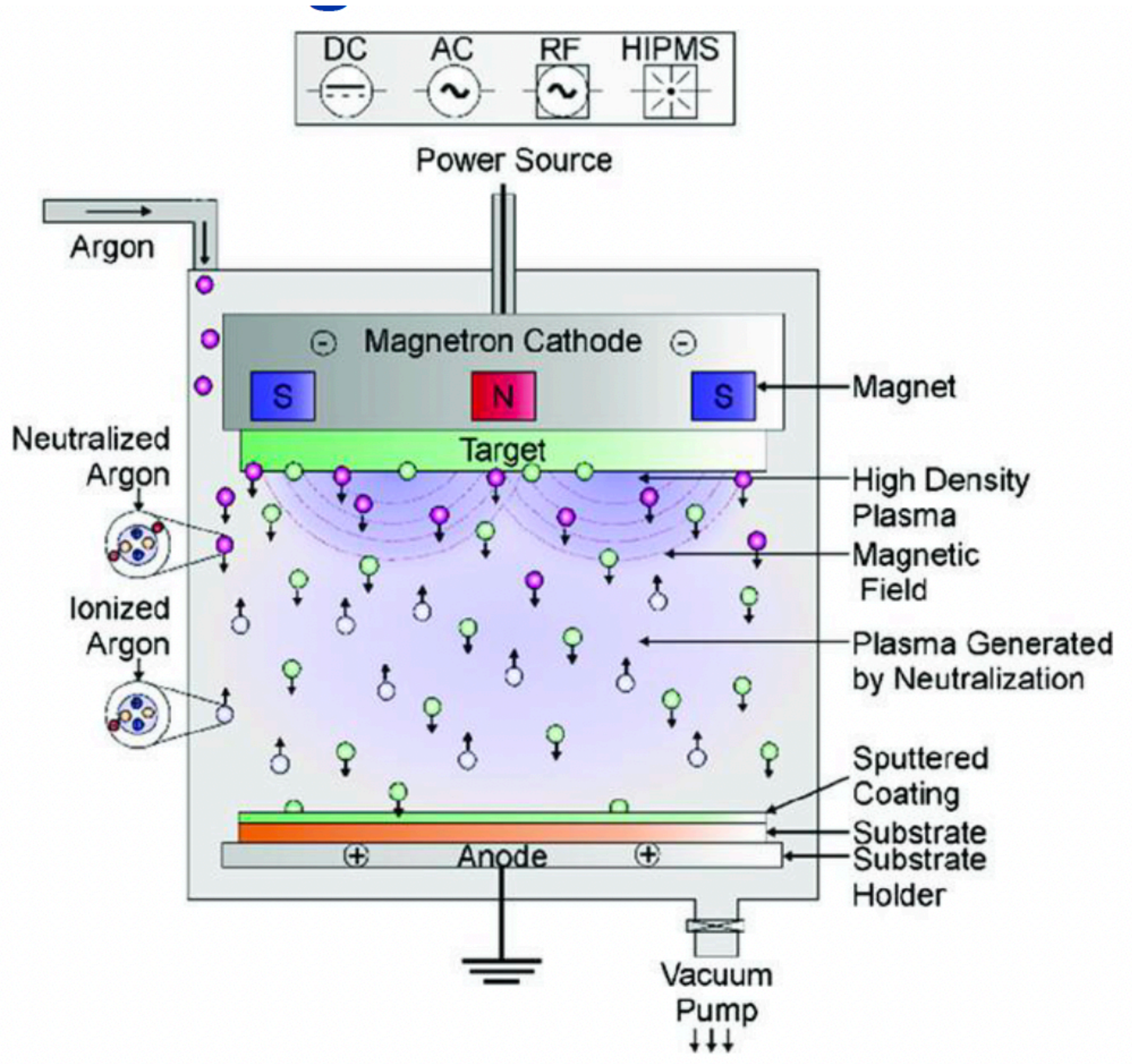
Limitations

- Rough surface
- Difficult to scale up

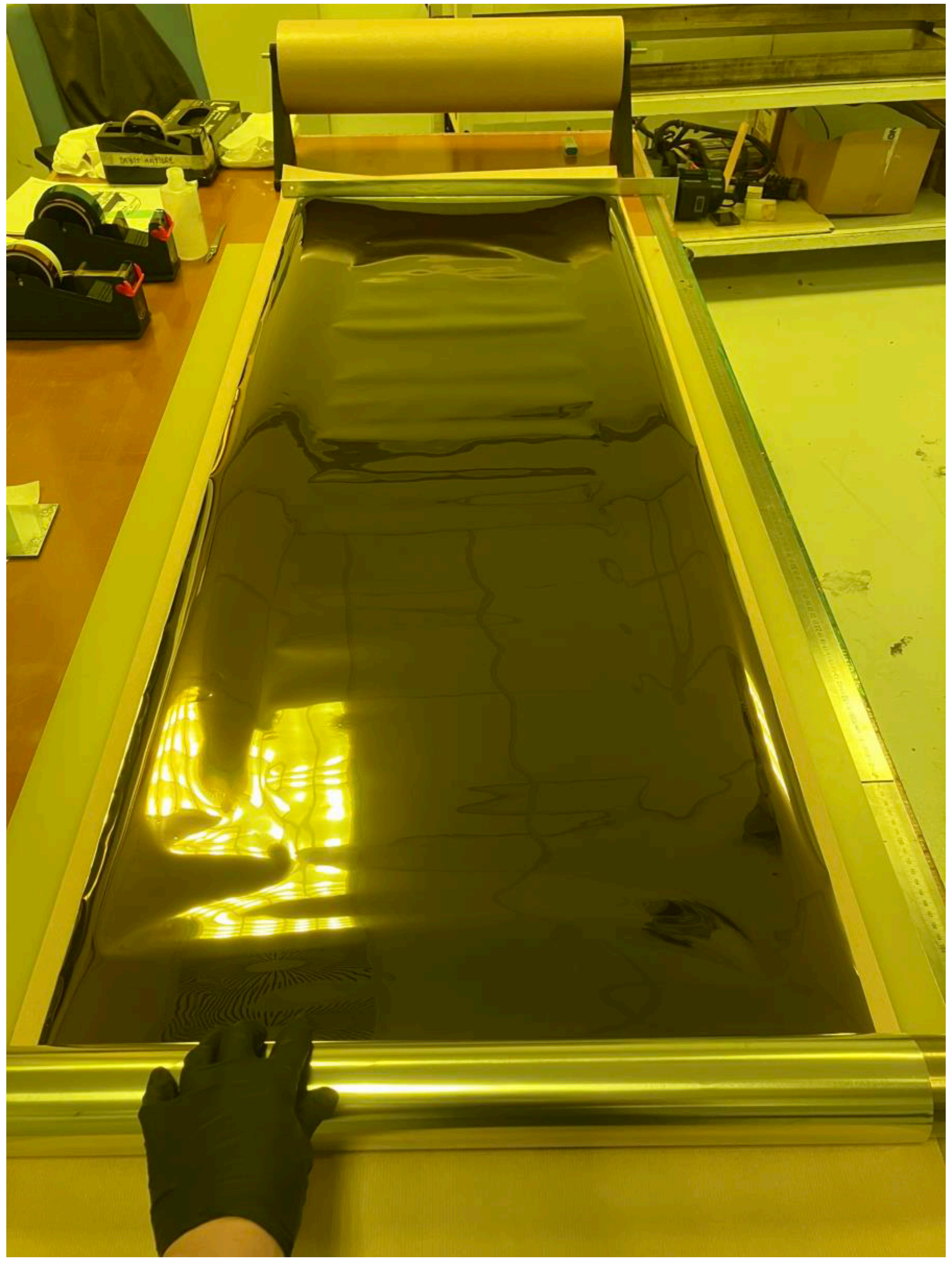
# Resistive layers

## DLC sputtering on Polyimide

**Magnetron sputtering**




**DLC on APICAL**



Advantages

- Good control on resistivity by gas chemistry
- Smooth surface
- Resistant to aging
- Implemented in standard PCB processes

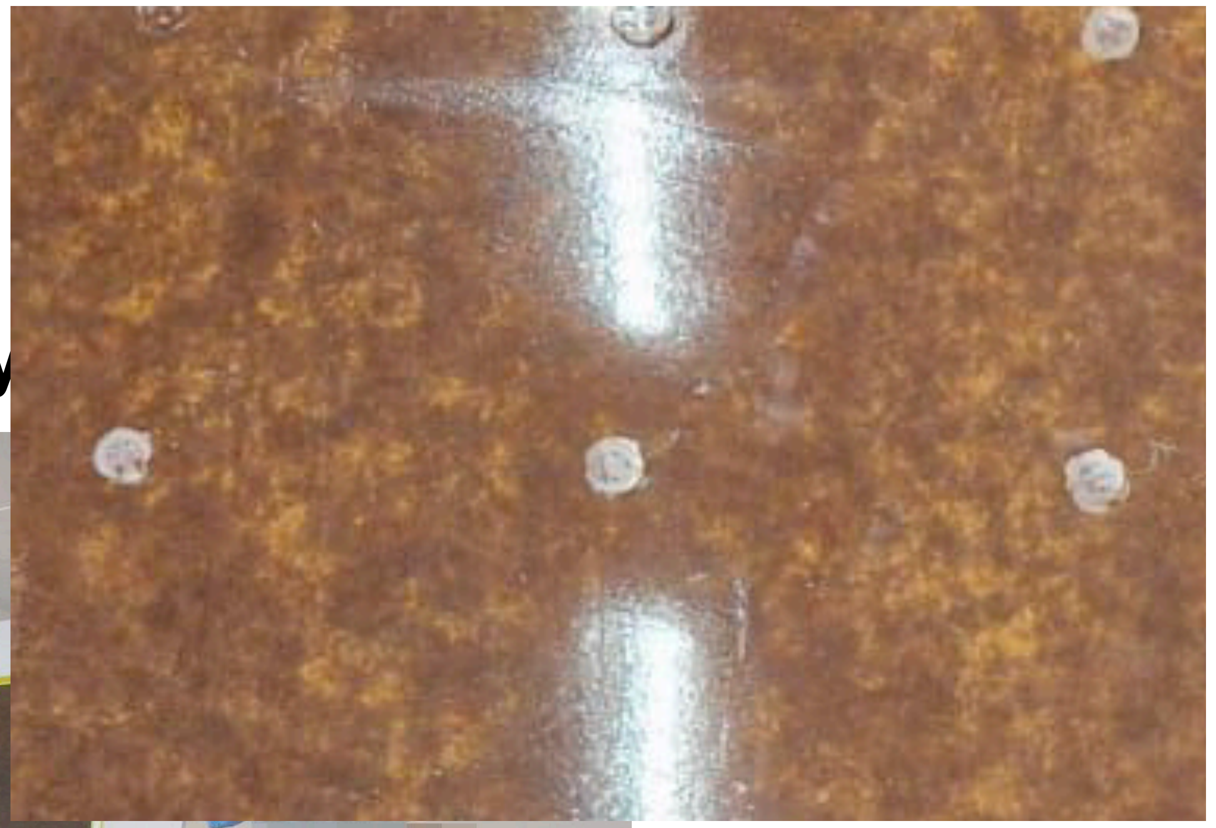
Limitations

- Costly machine and difficult to scale up

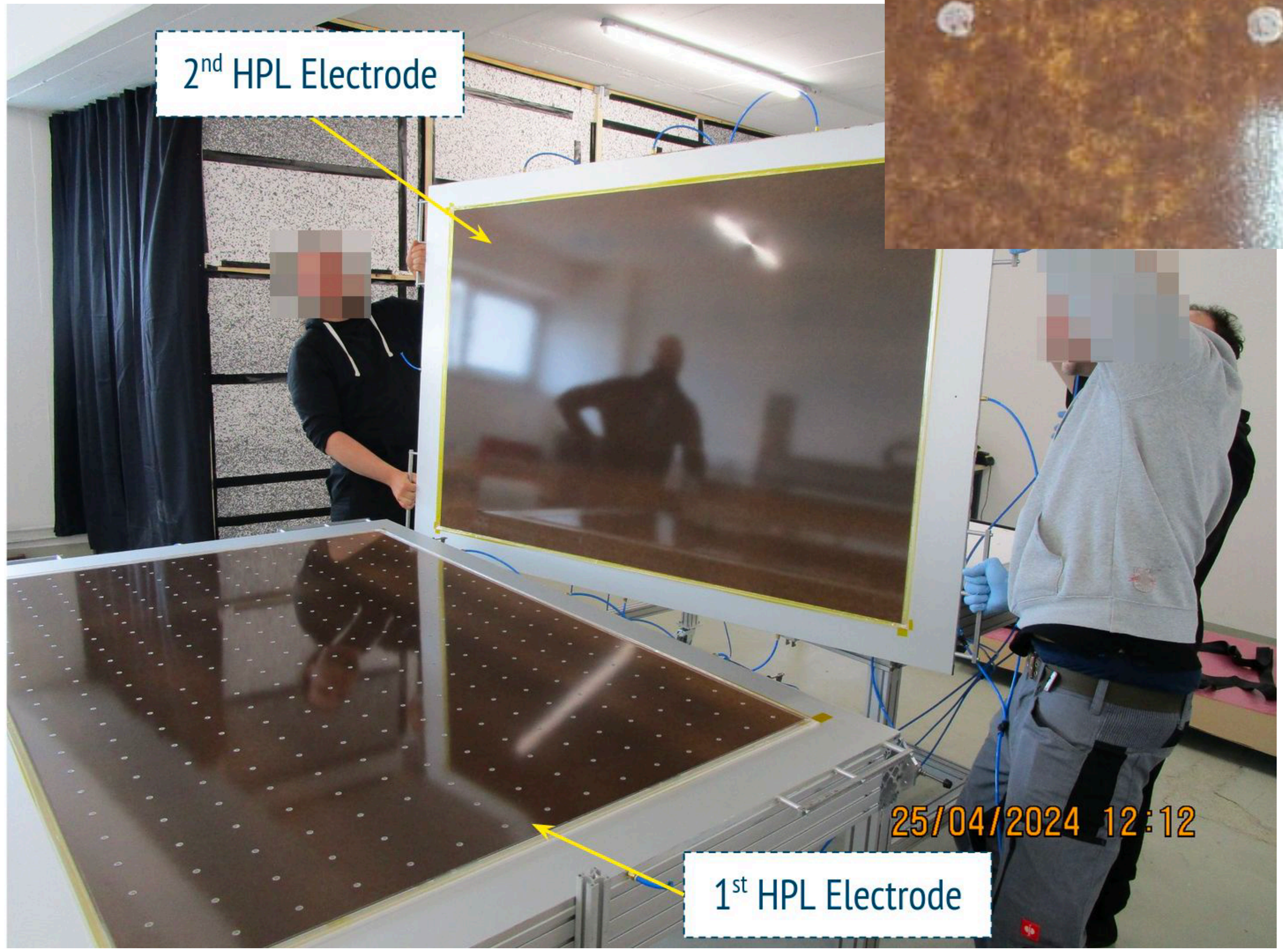
# Resistive plates

## Bakelite

**Bakelite surface roughness**



**Bakelite RPC assembly**




Advantages

- Easy to scale up
- Cheap

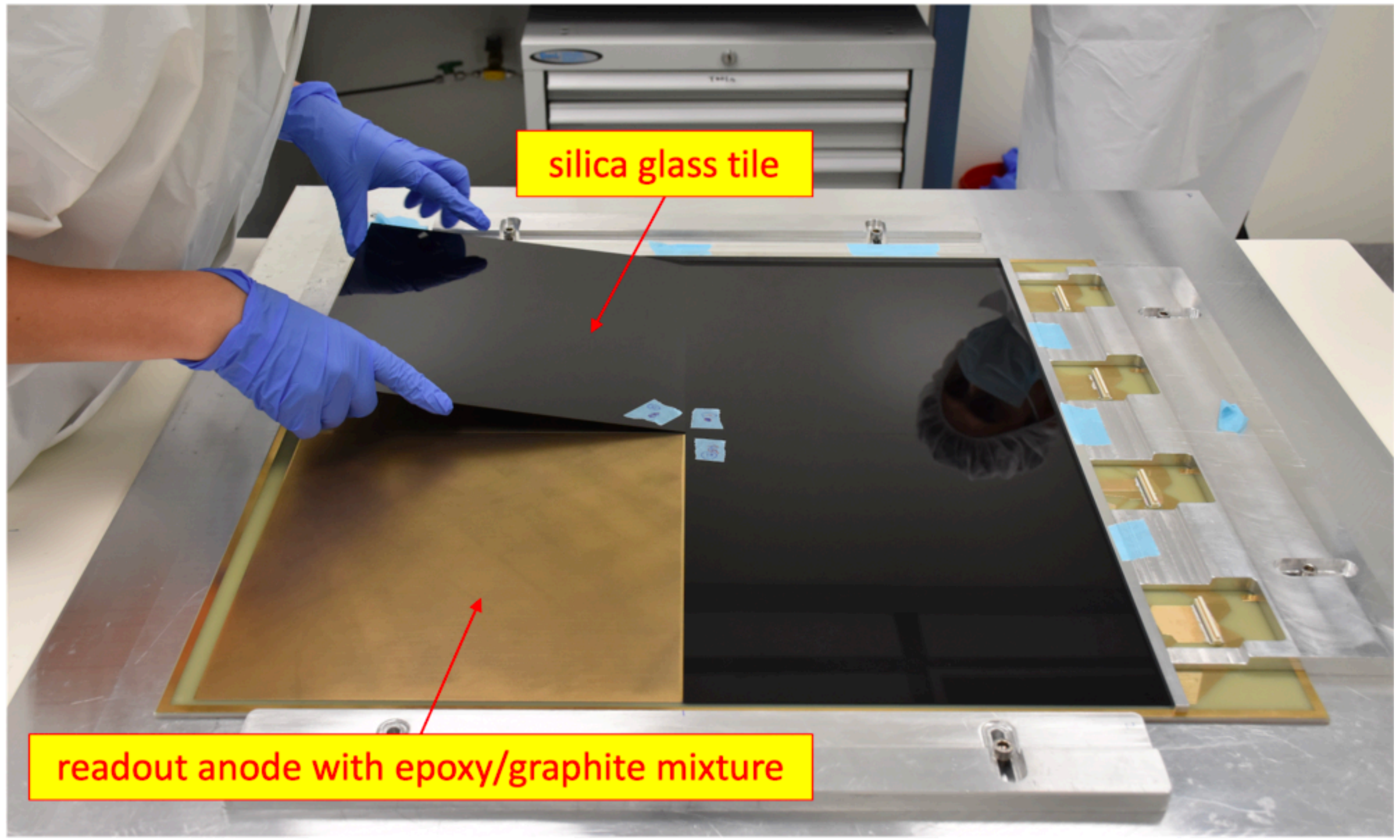
Limitations

- High resistivity with little tunability
- Not implemented in standard PCB processes
- Rough surface
(partially solved by polymeric coating)

# Resistive plates

## Glass

**Doped glass with low resistivity**




Advantages

- Smooth surface
- Cheap
- Easy to scale up

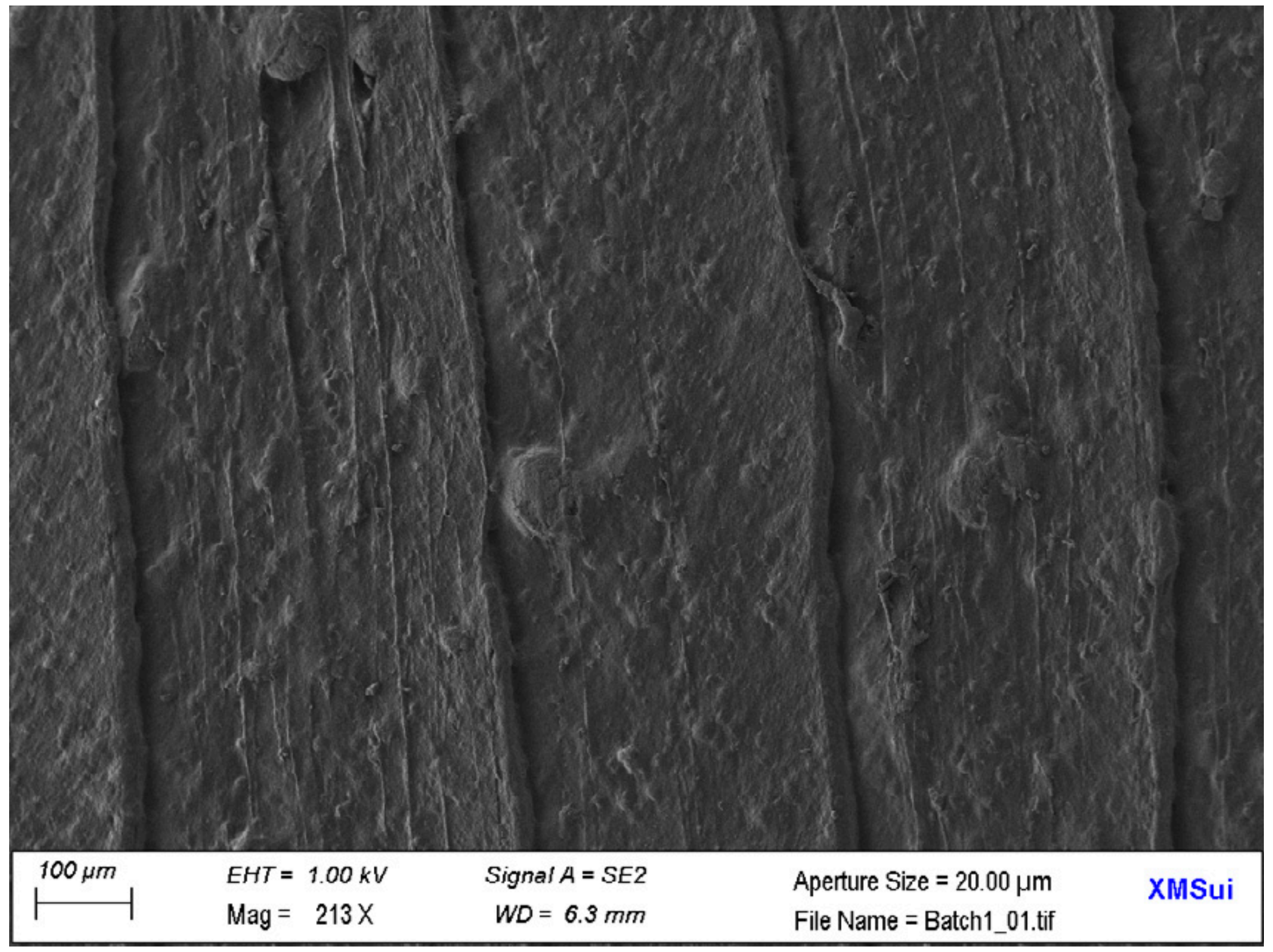
Limitations

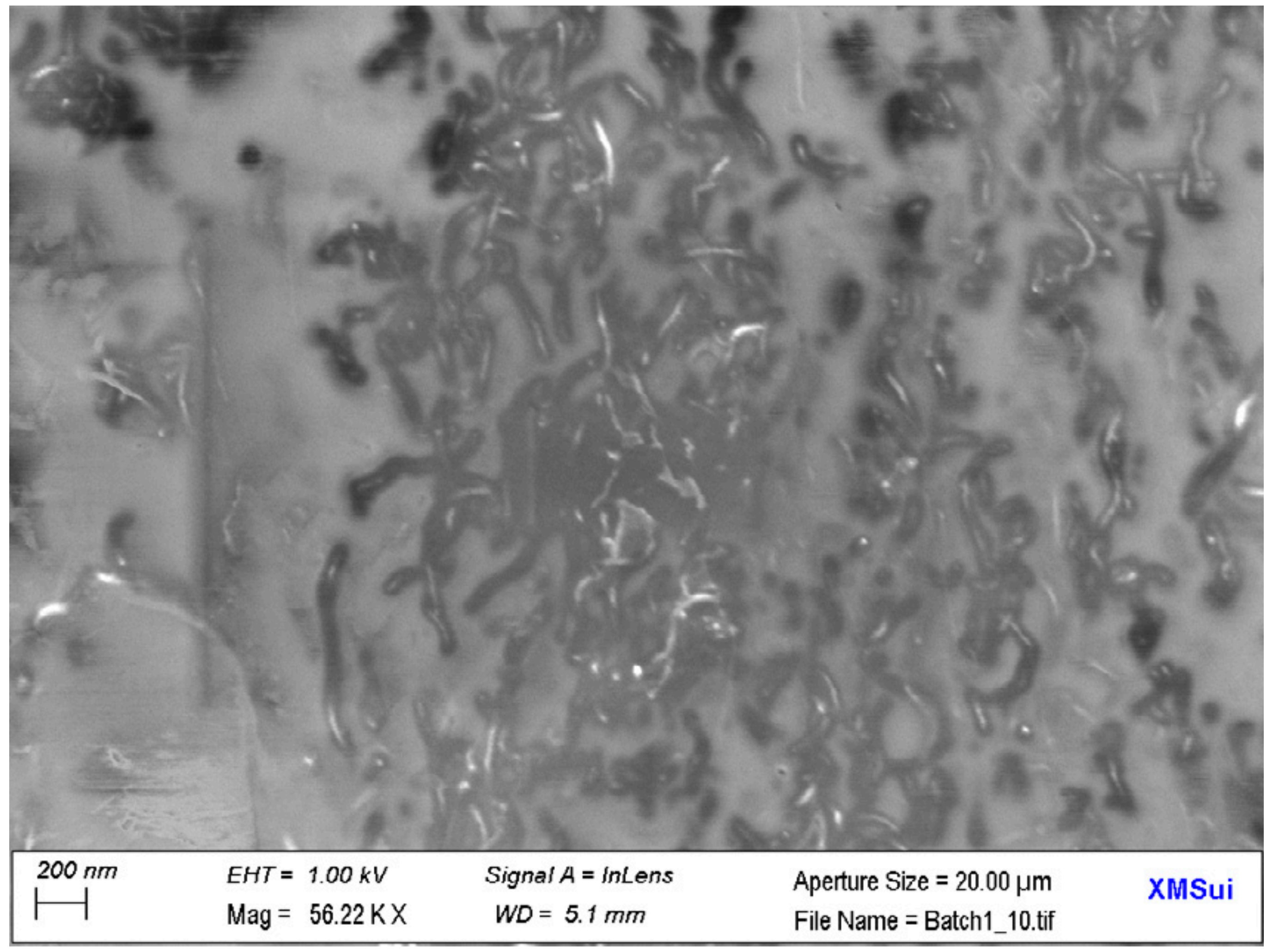
- Fixed resistivity
  - Normal glass: high resistivity
  - Doped glass: $2 \times 10^9 \ \Omega \cdot \mathrm{cm}$
- Not implemented in standard PCB processes
- Fragile

# Resistive plates

## Plastic materials

**3D printed plastic with CNT loading**




Advantages

- Different fixed resistivity values
- Cheap
- Easy to scale up
- 3D printable options
    - Tunable resistivity

Limitations

- Rough surface
- Plates commercially available with large thickness
- Not implemented in standard PCB processes
- Ageing, outgassing and radiation hardness

# Common project proposal

# R&D development: prepreg with tunable resistivity

**Prepreg** (*pre-impregnated composite fiber*): reinforcing fibers (e.g. carbon, glass, or aramid) pre-impregnated with a partially cured resin system (e.g. epoxy, phenolic, or thermoplastic).

- The resin can include additives (e.g., carbon black, CNTs, graphene, or metal particles) to impart controlled electrical conductivity or static dissipation.
- It is stored in a tacky, pliable state and requires heat and pressure to fully cure during molding or lamination.

| Advantages | Limitations |
| --- | --- |
| • Resistivity tunable by additives<br>• Cheap<br>• Easy to scale up<br>• Standard PCB substrate<br>• Robust against aging, discharges, radiation<br>• Mature technology used in most gaseous detectors | • Resistive tunability not commercially available<br>• Nontrivial surface and bulk properties of a composite material<br>• Handling and storage conditions before curing<br>• Complex process requiring industrial equipment (dispersion of additive in resin, fiber impregnation, curing under pressure and heat) |

# Possible partners

## Industrial

- Contacted tens of companies in the field with no positive response
  - Development of custom material is expensive → no commercial revenue
  - Custom R&D done for aerospace and defense → not public
  - Some companies provide resistive laminates already cured and with large spread of resistivity from sample to sample
- Collaboration with industry is crucial, but it should be done through intermediary institutions

# Possible partners

## Academic

- Several academic groups and institutions are willing to collaborate
- There are other institutions in Germany that might be interested

| Partner / Contact | Status | Notes |
|---|---|---|
| IPCB-CNR (M. Giordano, E. Bemporad) | Awaiting interest confirmation | collaborating with small producers |
| Politecnico di Milano (R. Frassine, M. Longana) | Industry contacts, sent specs, they will inquire | no capabilities in house |
| University of Bologna (E. Troiani) | Follow-up meeting after presentation | collaborating with small producers |
| CETMA (A. Passaro) | Awaiting proposal for R&D costs | research institution offering R&D services |
| Ben-Gurion University (O. Regev) | Produced CNT loaded epoxy | no prepreg facility |
| Shenkar College (N. Naveh) | Considering how to collaborate | small custom prepreg production and knowhow |
| SINANO (Weibang Lv) | Will produce samples of CNT prepreg | developed CNT dispersions and prepreg |
| Leibniz-IVW (J. Schlimbach via M. Gurka) | Replied with questions, technical exchange ongoing | |

# Project outline

- **3 institutes** involved (regular members of DRD1): WIS, MPI, CERN EP-DT-EF
- **Budget**: 40 kCHF/year for 2 years
  (At least 50% of the total cost is provided by the participating institutes)
- **Core objectives**
  - Design and fabricate prepregs with surface resistivity in the range of $10^5$–$10^9 \Omega/\square$ and/or bulk resistivity in the range of $10^9$–$10^{11}$ Ω·cm for the cured laminate
  - Ensure compatibility with large-area electrode assembly, including flatness, mechanical strength, and stability
  - Identify and validate scalable production processes through collaborations with academic labs and industry partners
- **Working plan**
  - 1st year: Tunable resistivity prepreg production (A4-size repetitions), curing and lamination by suitable selected companies
    - Test different additives (e.g. CNT, nano-powders)
  - 2nd year: Tunable resistivity prepreg integration in electrodes and detectors' prototyping
    - e.g. 10 × 10 cm with strip readout, with resistive layer or resistive plate
    - Fabrication of small detector prototypes, RPC, TGC, RPWELL

# Thank you.

# Any questions and suggestions are welcome anytime