FACULTY OF ELECTRICAL ENGINEERING
UNIVERSITY OF WEST BOHEMIA

RICE

Faculty of Electrical Engineering
University of West Bohemia

DIELECTRIC MATERIALS DIAGNOSTICS IN ELECTRICAL ENGINEERING

Josef Pihera
Department of materials and technologies

www.rice.zcu.cz

MINISTRY OF EDUCATION, YOUTH AND SPORTS
EUROPEAN UNION
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Short introduction - Pilsen

2015 Pilsen
European Capital of Culture



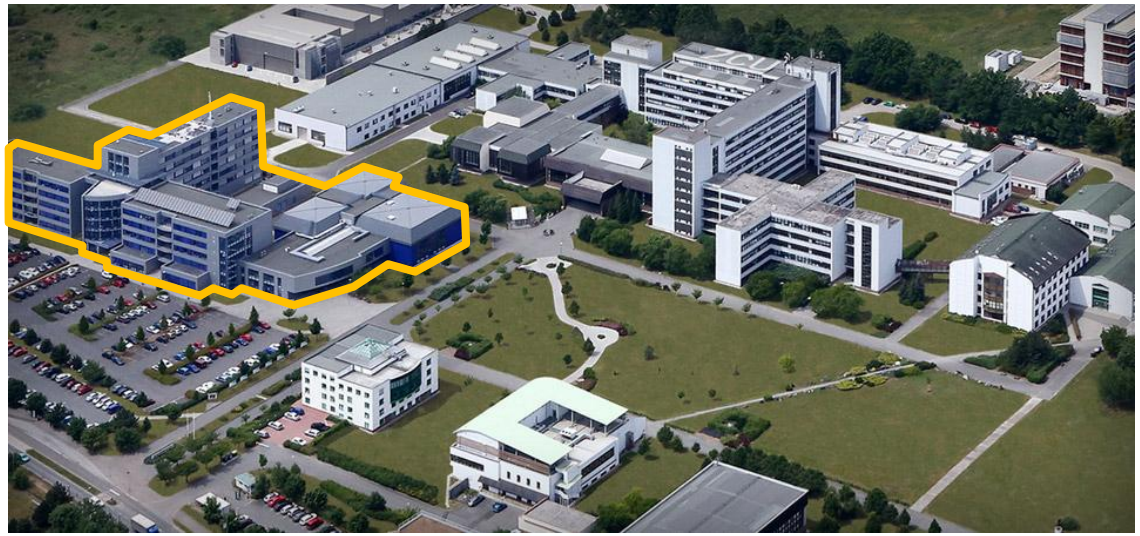



Short introduction – Uni Pilsen

University of West Bohemia

City	Pilsen (CZ)
Founded in year	1991 (1950)
Number of employees	2100
Number of students	12 000 / 1000

Faculty of Electrical Engineering (FEE)



R&D areas of the Material research and Diagnostics group

R&D areas of working groups at KET department

Printed and Flexible electronics – Interconnections, passives (LRC), sensors, transistors (OECT), batteries.

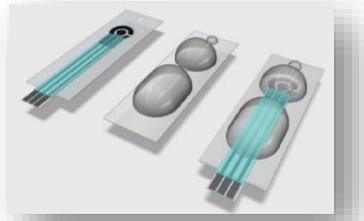
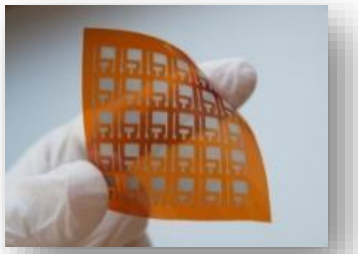
Smart Textiles – Interconnection systems, functional structures on textile, integration of electronic blocks, wireless communication, sensor evaluation circuits.

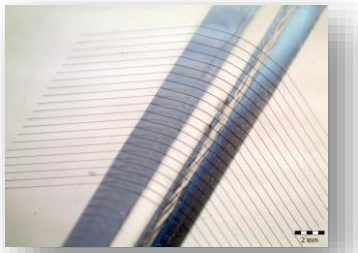
Sensors – Vapour and gas (chemoresistive, electrochemical), temperature, humidity, mechanical.

Flexible Hybrid Systems - Integration of SMDs and printed electronics into systems-on-foil.

Low cost manufacturing technologies – Aerosol Jet Printing (OPTOMEC 300), Screen printing (EKRA E2)

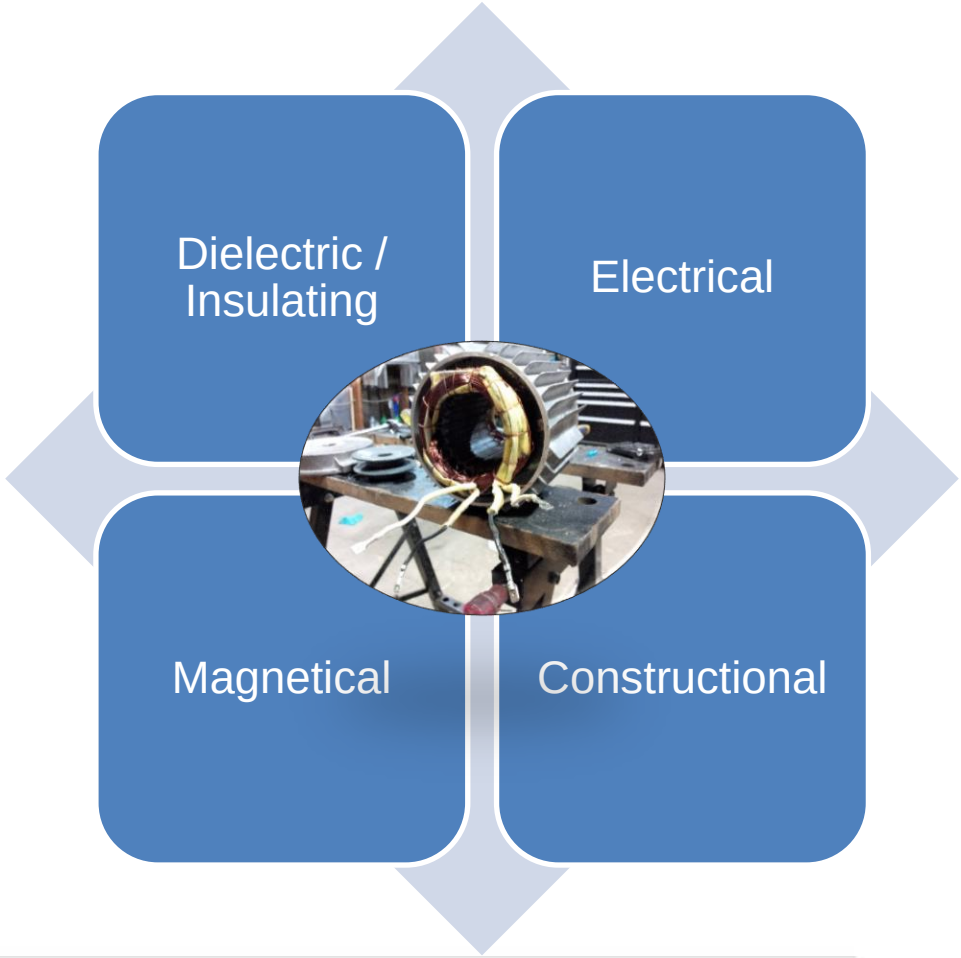
Diagnostics – online resin curing monitoring, thermal analyses tests, mechanical tests, electrical behaviour, environmental testing, acoustics measurement, vibrations, printed circuit boards (PCB) testing, solder joints tests, high voltage diagnostics

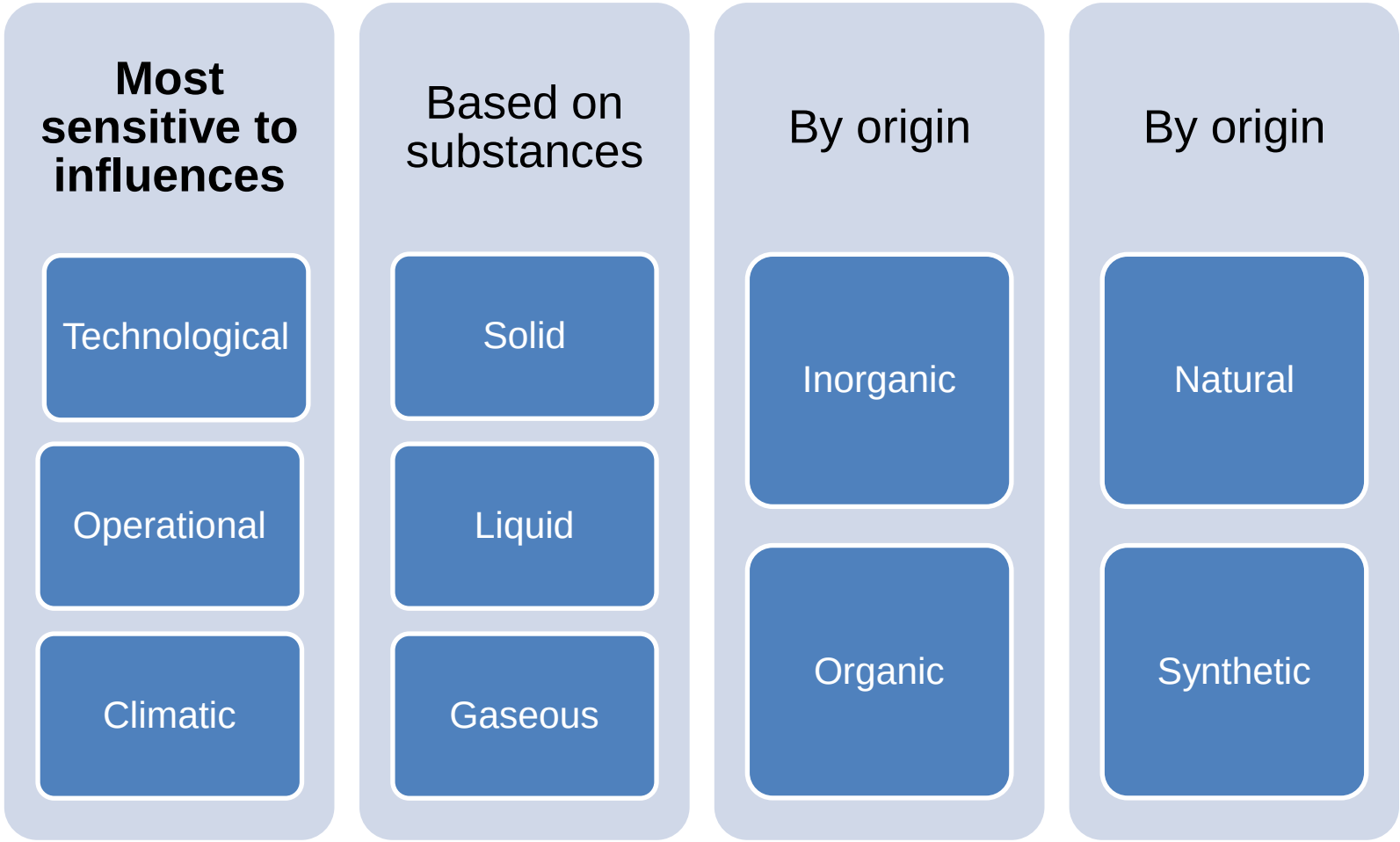



Electrical engineering systems

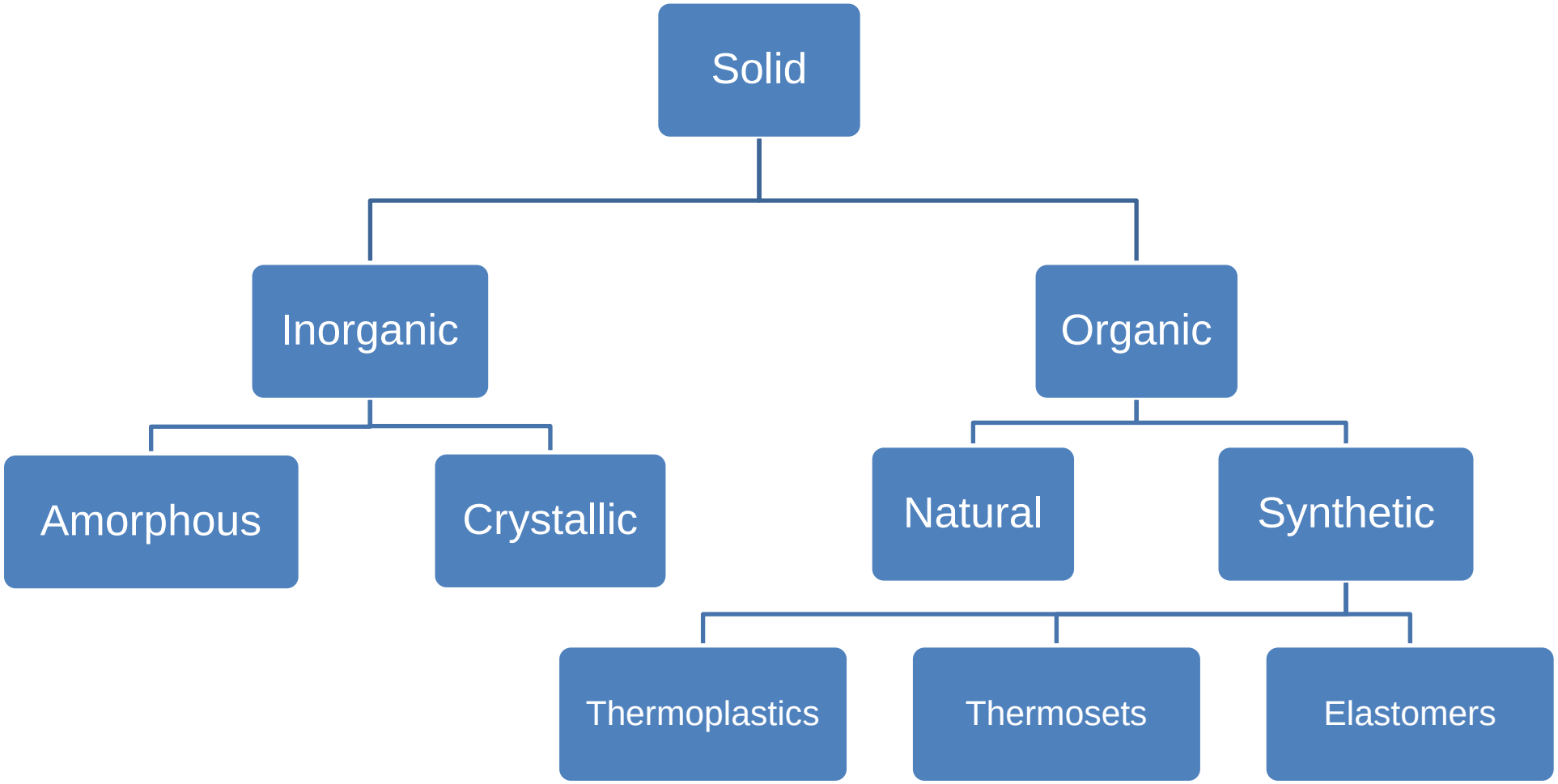
Electrical engineering system consists of elementary key subsystems



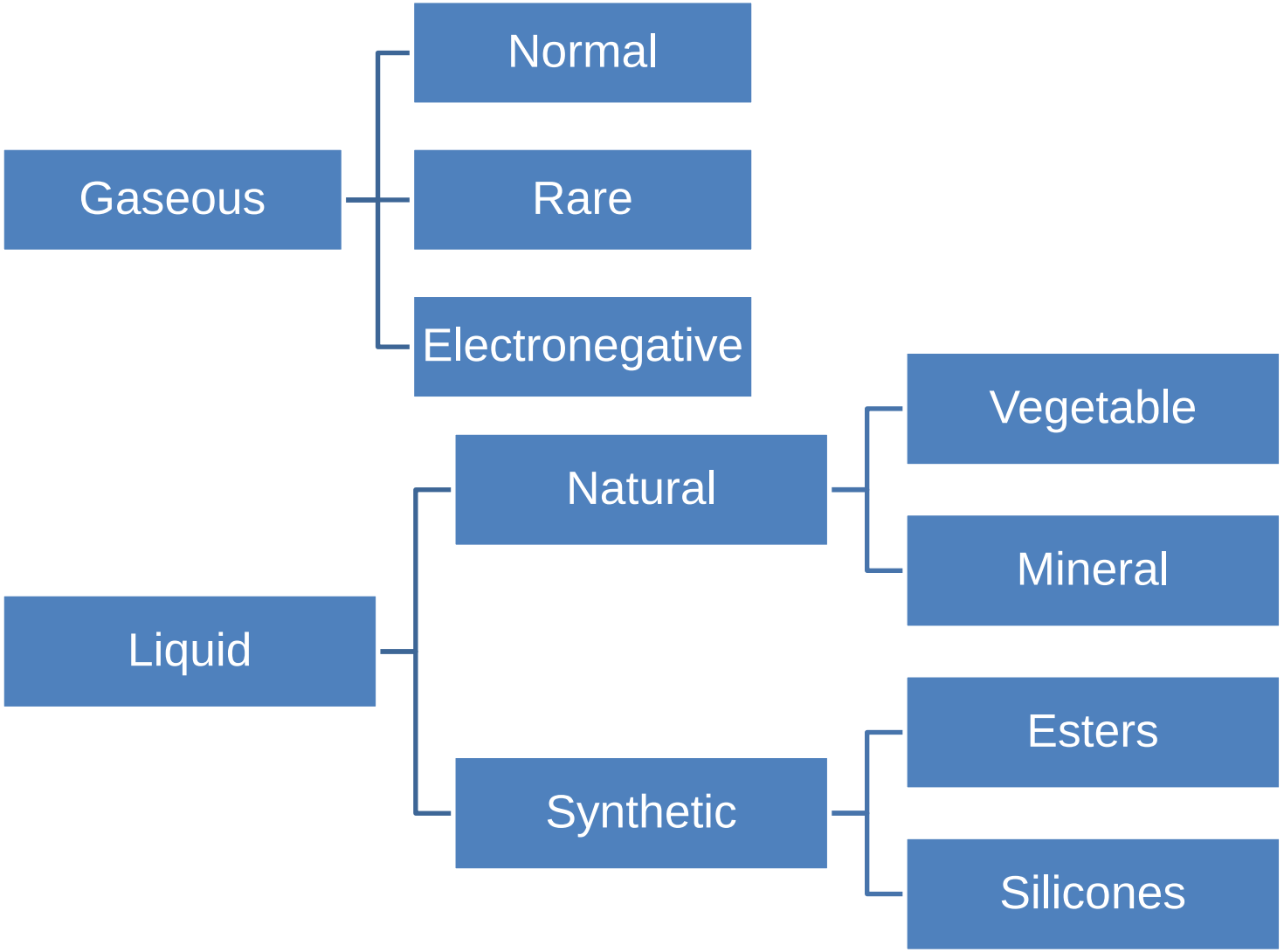
Insulating system



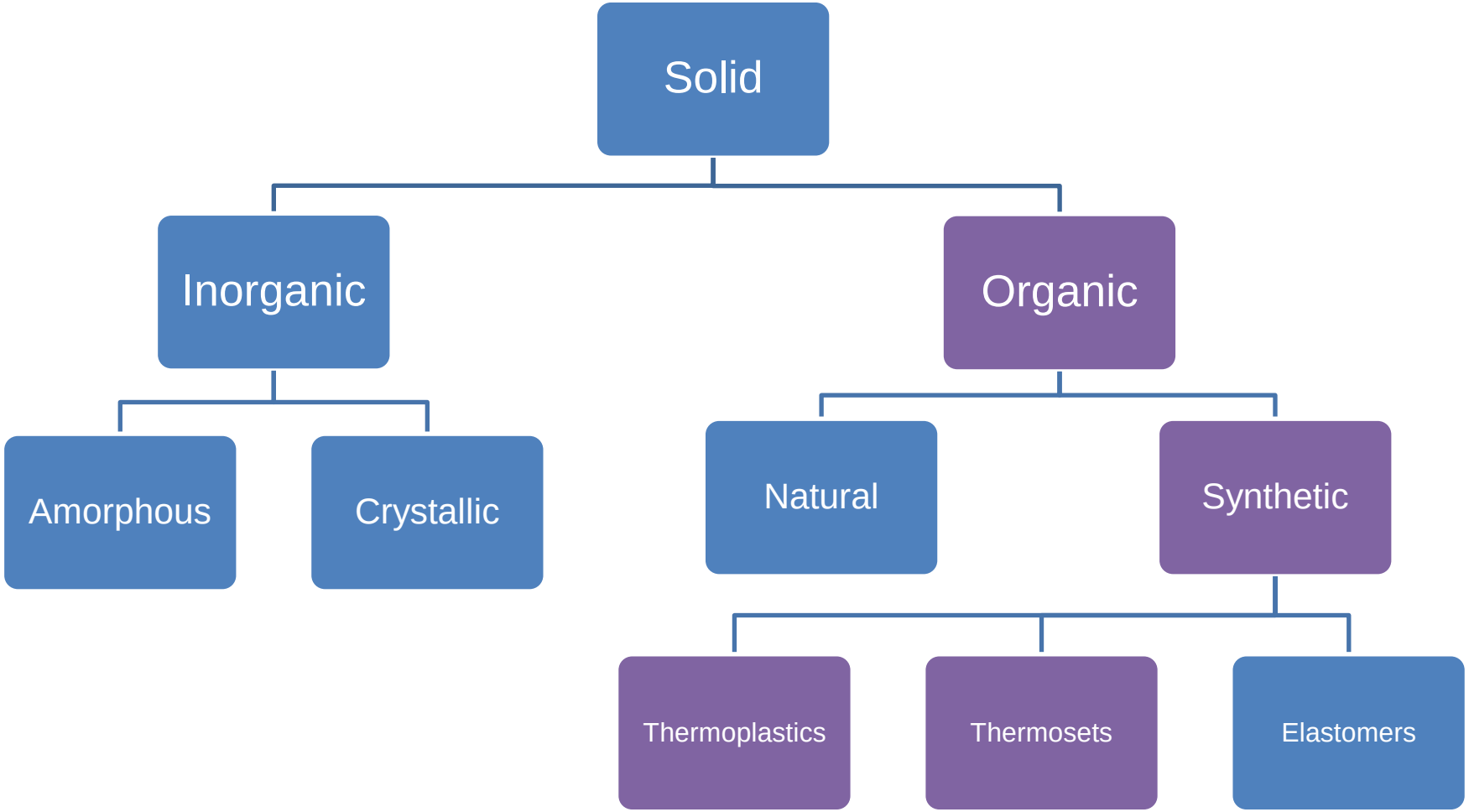
Insulating system



Insulating system

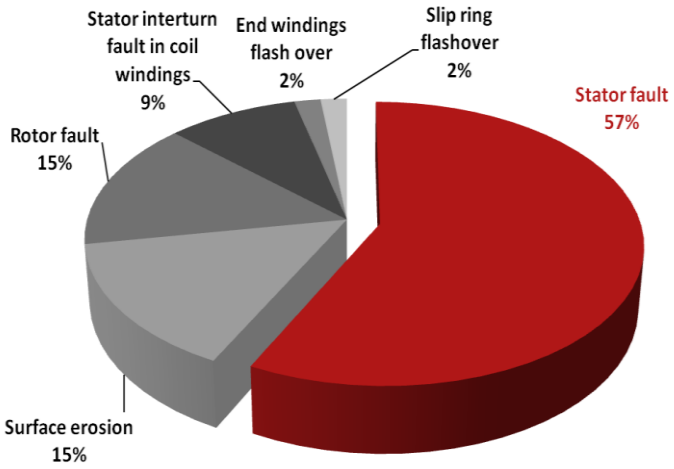


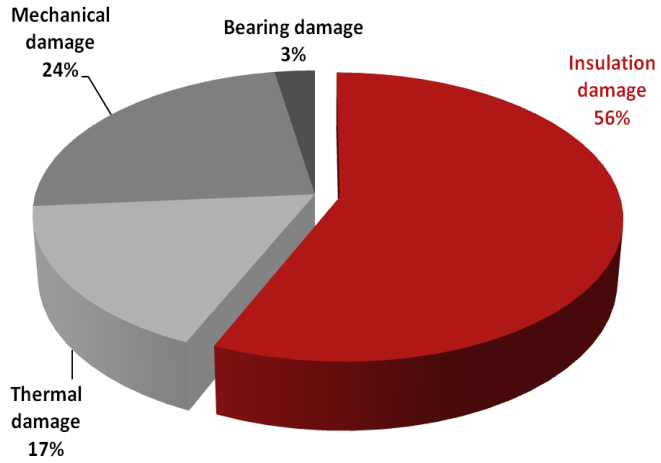
Homogeneity / quality of insulating system

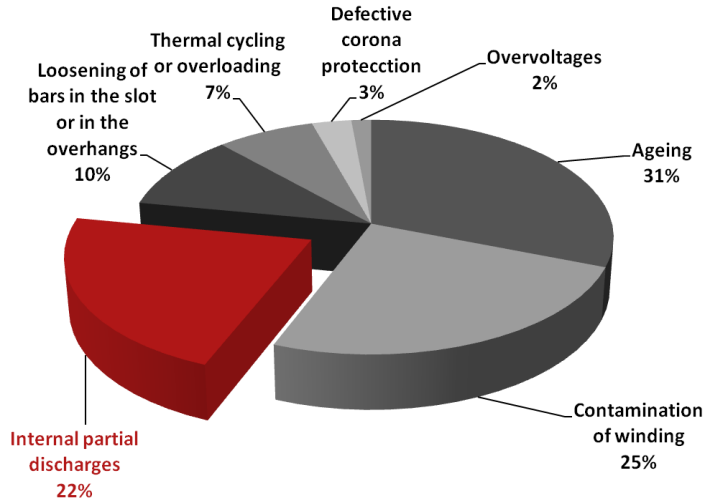


Homogeneity / quality of insulating system

Rotating machines faults



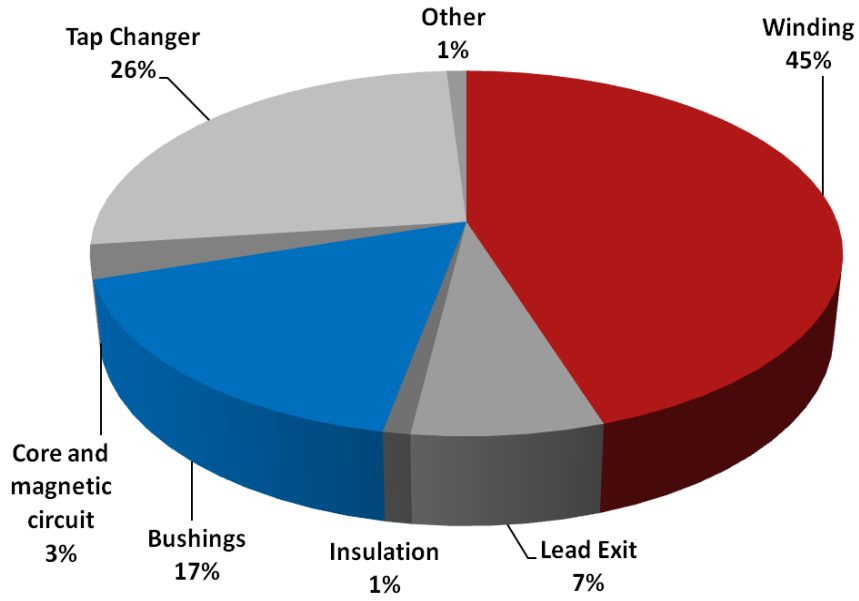




[Cigre Brochure WG A1.10: Survey of Hydrogenerator Failures, 2009, p. 22]

Homogeneity / quality of insulating system

Transformer faults



[Cigre Electra WG A2.37: Transformer Reliability Survey: Interim Report. 2012, p. 4]

Diagnostics

- Use for recognition of the condition of technical systems
- To identify, to check and to classify characteristics of the condition of systems
  - to change or to influence the condition of these systems
- Quality assurance of technical systems
- Avoidance of an outage of technical systems

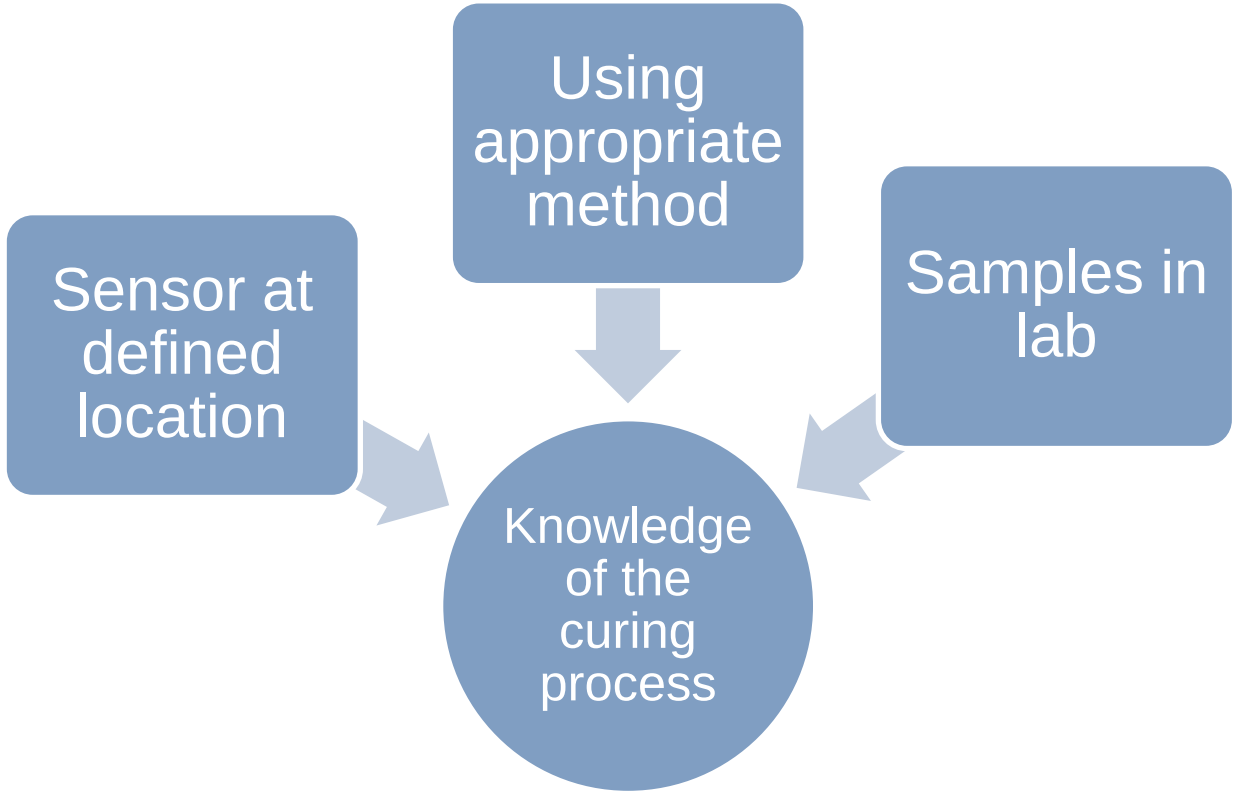
Diagnostics

Diagnostic methods in electrical engineering

Electrical methods	Dielectric loss diagnostics
	Partial discharge diagnostics
	Breakdown / withstand voltage diagnostics
	Resistivity
Mechanical testing	Analysis of mechanical quantities
	Dilatometry
	Mechanical spectrometry
	Sound emission analysis
Visual inspection	Direct inspection
	UV inspection
	IR inspection
	X-ray
Thermal diagnostics	Temperature measurement
Analytic and spectrometry	Structural analysis
	UV, VIS, IR - Spectrometry
	Gas chromatography
	Mass spectrometry

Curing monitoring

Curing monitoring

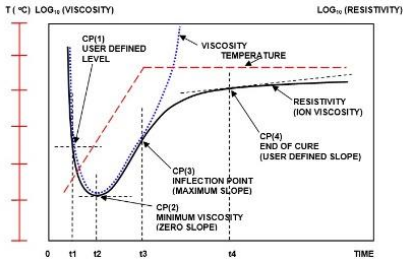


Curing monitoring

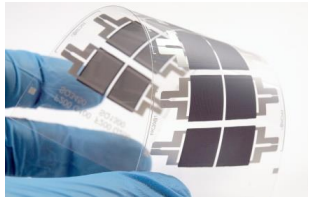
Structural analysis

- DSC
- TG
- DMA
- FTIR

Dielectric analysis (DEA) - on material samples



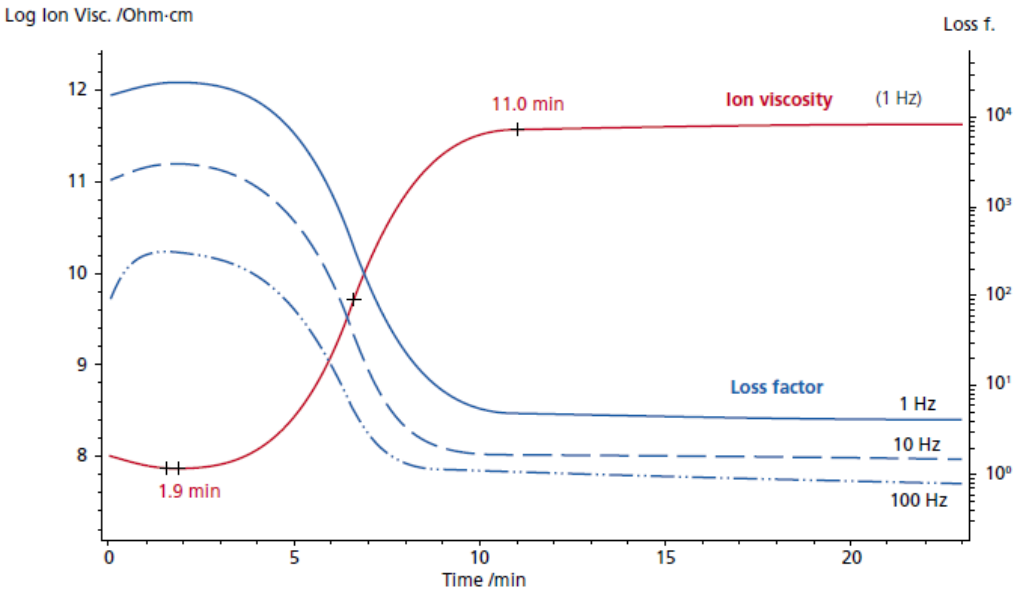
DEA using sensors



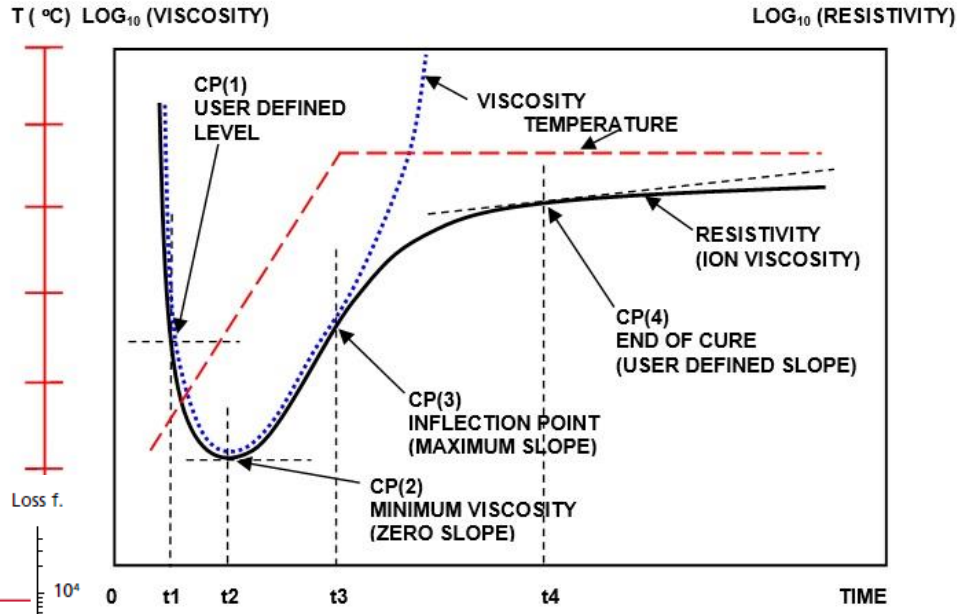
Different methods

Curing monitoring

Dielectric analysis



https://www.netzsch-thermal-analysis.com/media/thermal-analysis/brochures/DEA_288_Ionic_en_web.pdf



https://lambient.com/what-is-dielectric-cure-monitoring

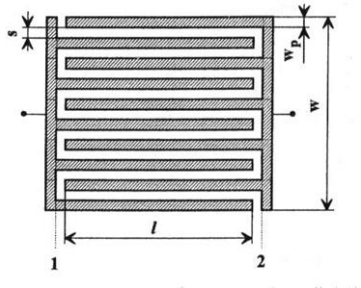
Curing monitoring

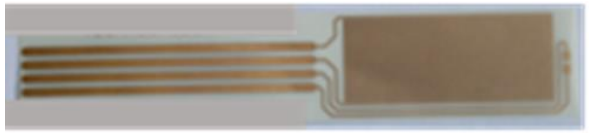
Development of online curing monitoring system ICM

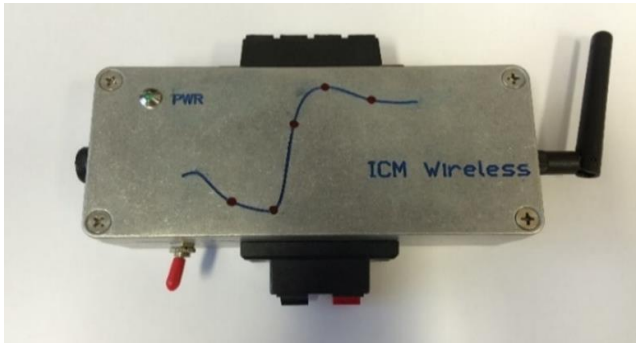
- Ceramics sensors
- Flexible sensors

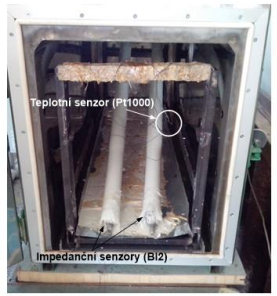
- Portable
- Modular
- Wi-Fi

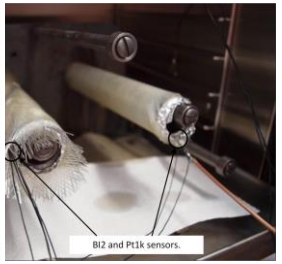
- Labs
- Product lines

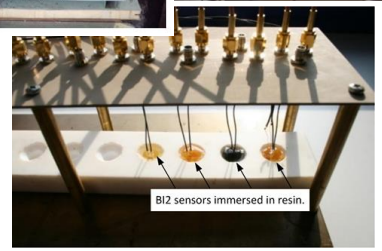








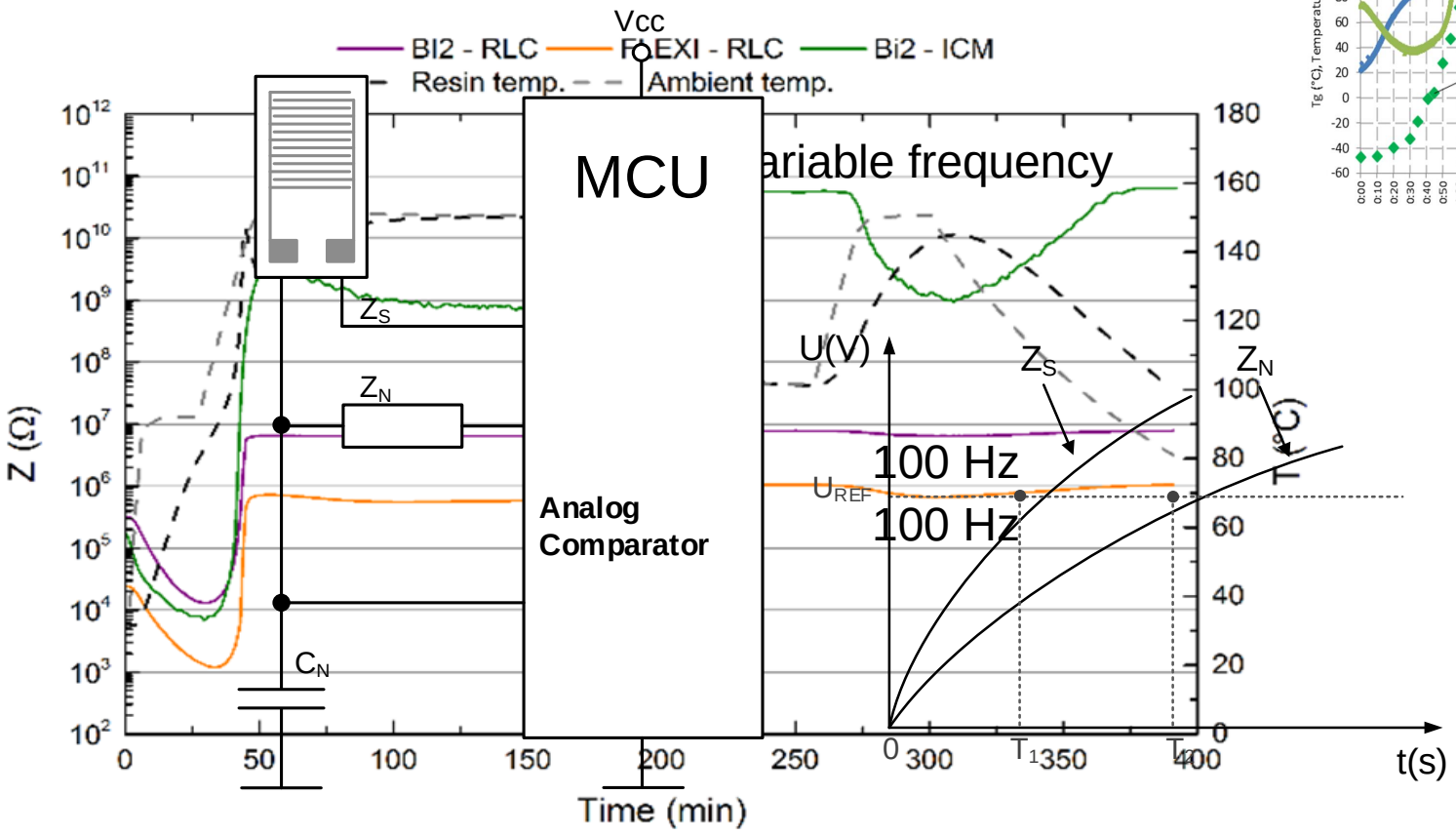


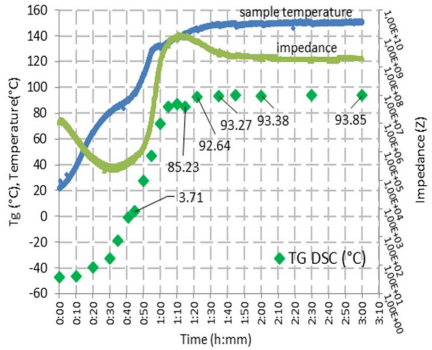


[1] R. Polanský et al., "Development of a measuring system for on-line in situ monitoring of composite materials manufacturing," Compos. Part A Appl. Sci. Manuf., vol. 90, pp. 760–770, 2016.

Curing monitoring

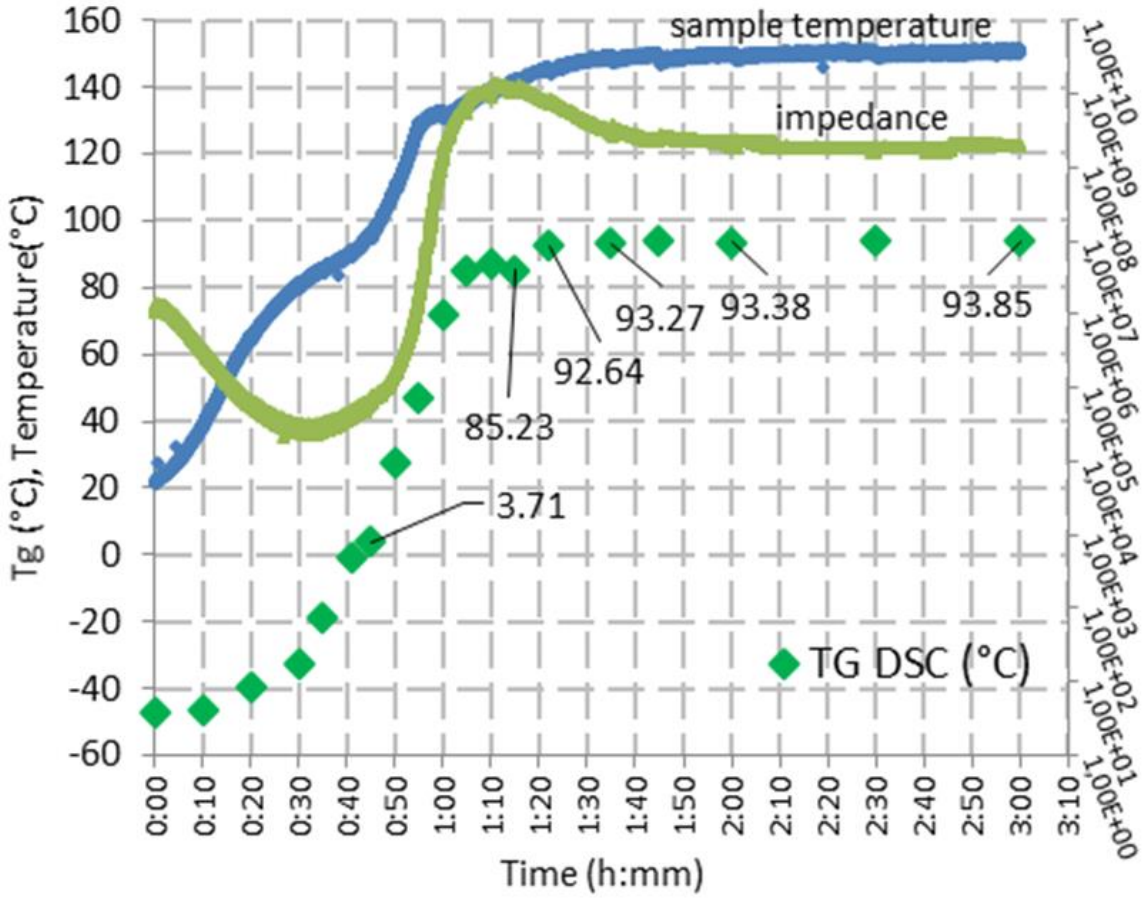
- **Improved sensitivity**
  - resin structure feedback

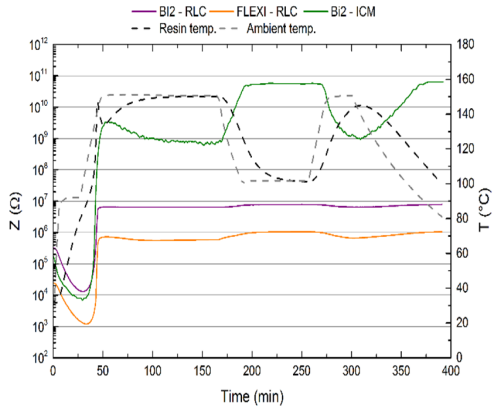




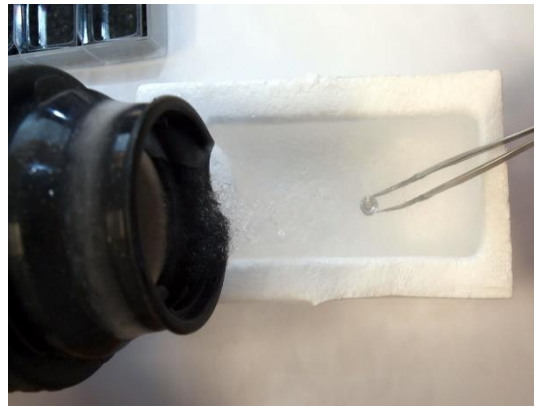
Curing monitoring

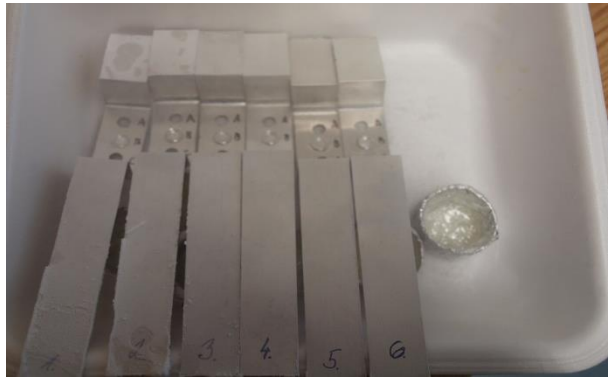
- **Improved sensitivity**
  - resin structure feedback





- **Liquid nitrogen – stop the reaction at each point**
- **DSC - Tg verification**

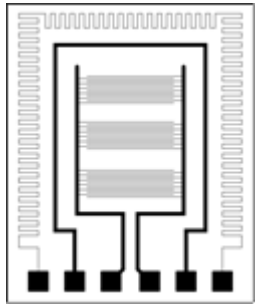


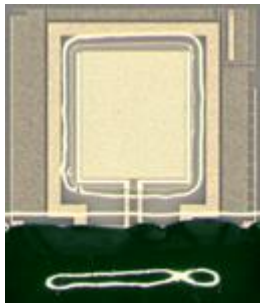


Curing monitoring

Development of on sensor curing monitoring ICM based system

- Combined sensor
  - Temperature sensors
  - IDE electrode
  - Heating element

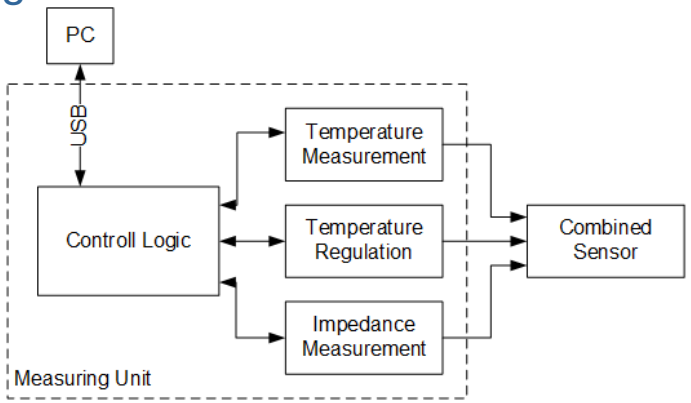




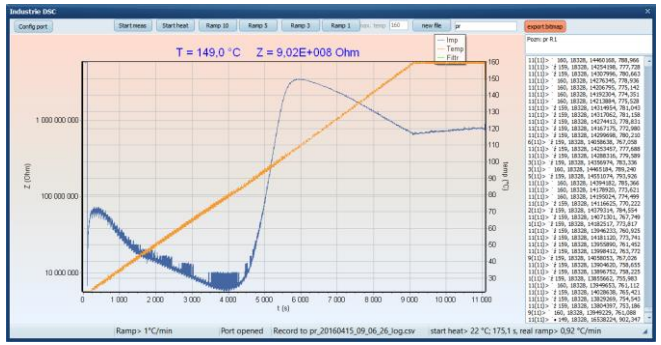
The sensor dimensions are 5 x 6 mm.

- Covered by a glass frit
  - prevent electrical interaction after applying the measuring medium

- Labs
- Production hall

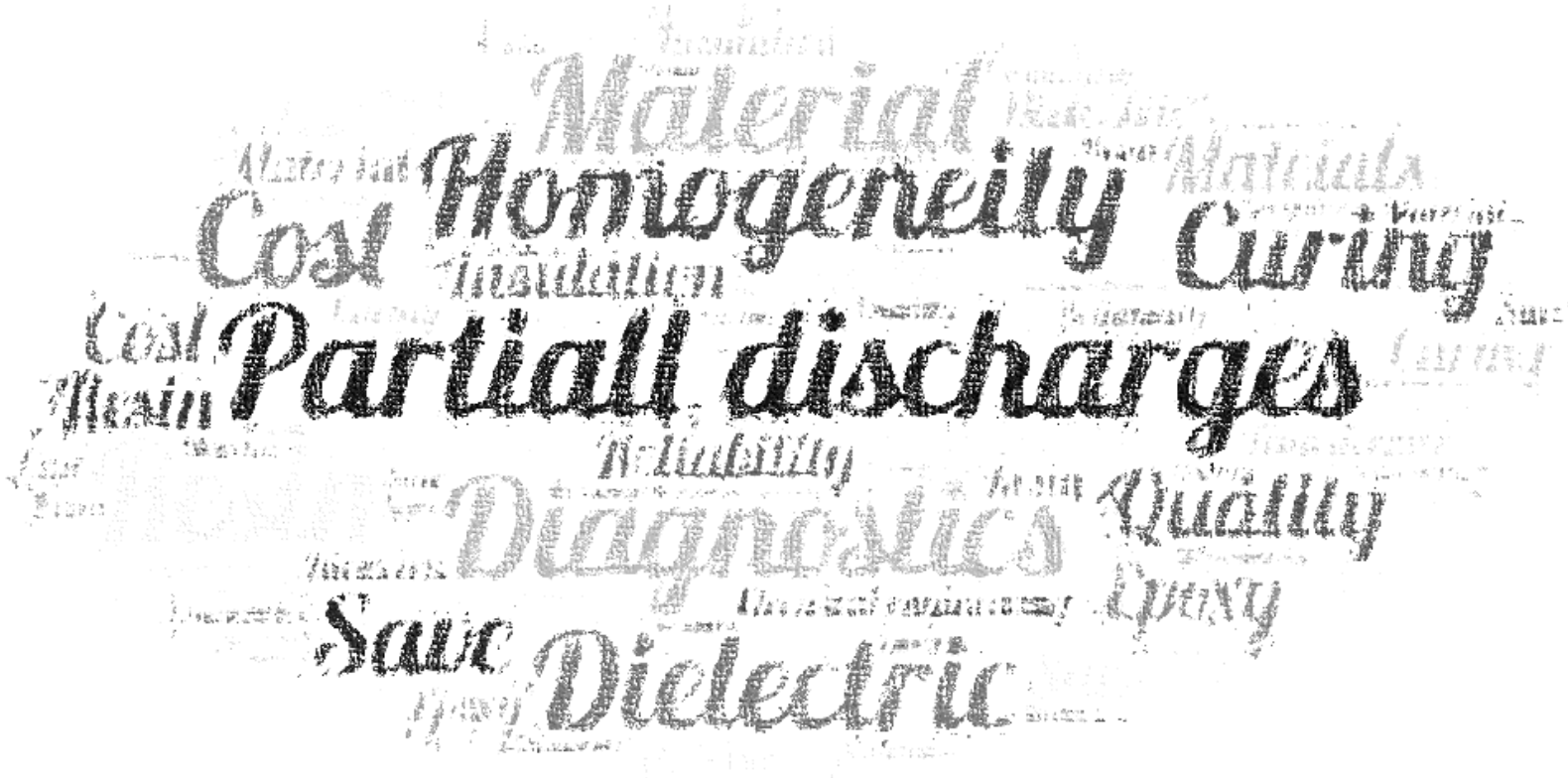


Temperature ramp: up to 10°C / min

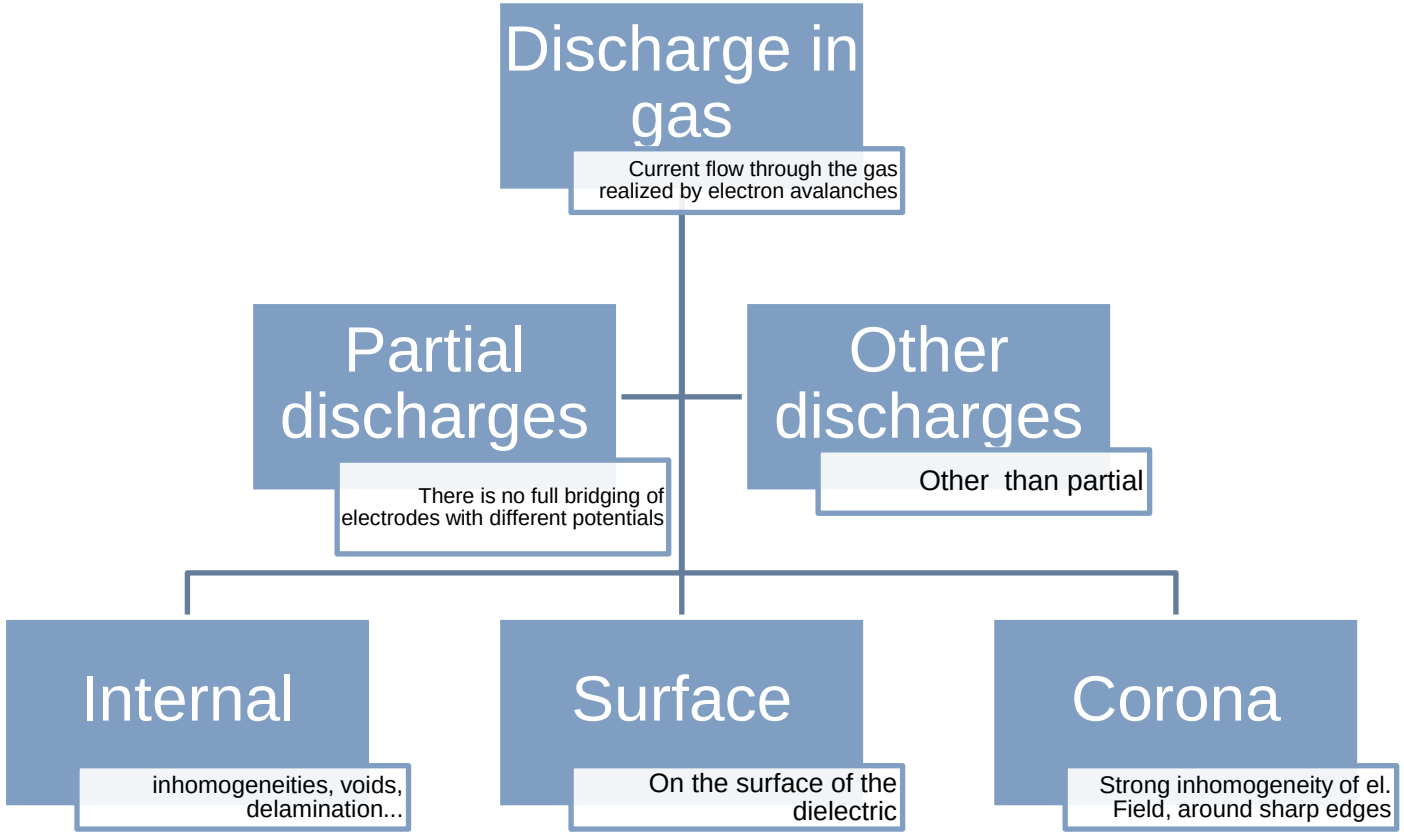


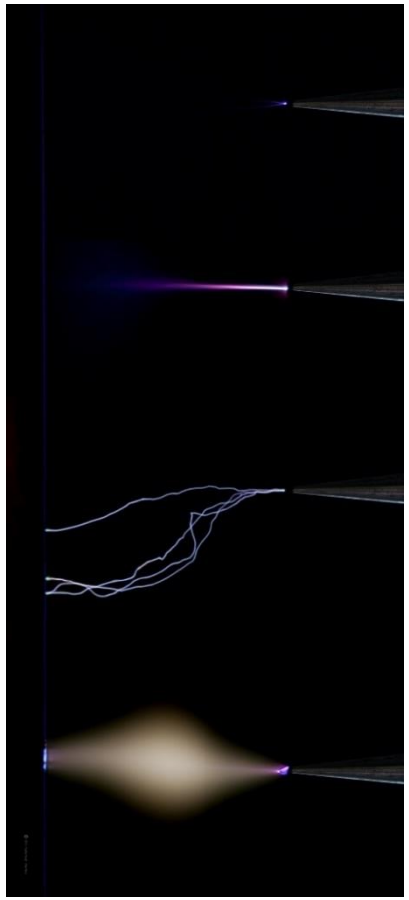
Homogeneity / quality of insulating system

When the system is cured



Partial discharges





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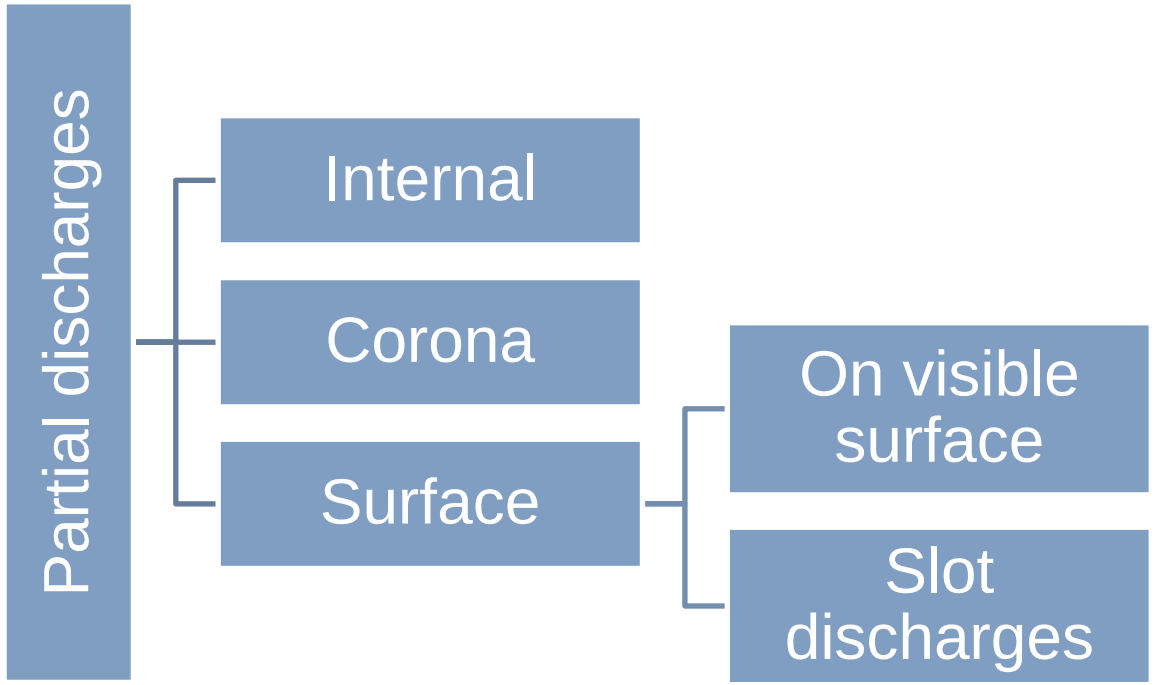
Partial discharges

- local electrical discharges that only partially short-circuit the insulator between the electrodes



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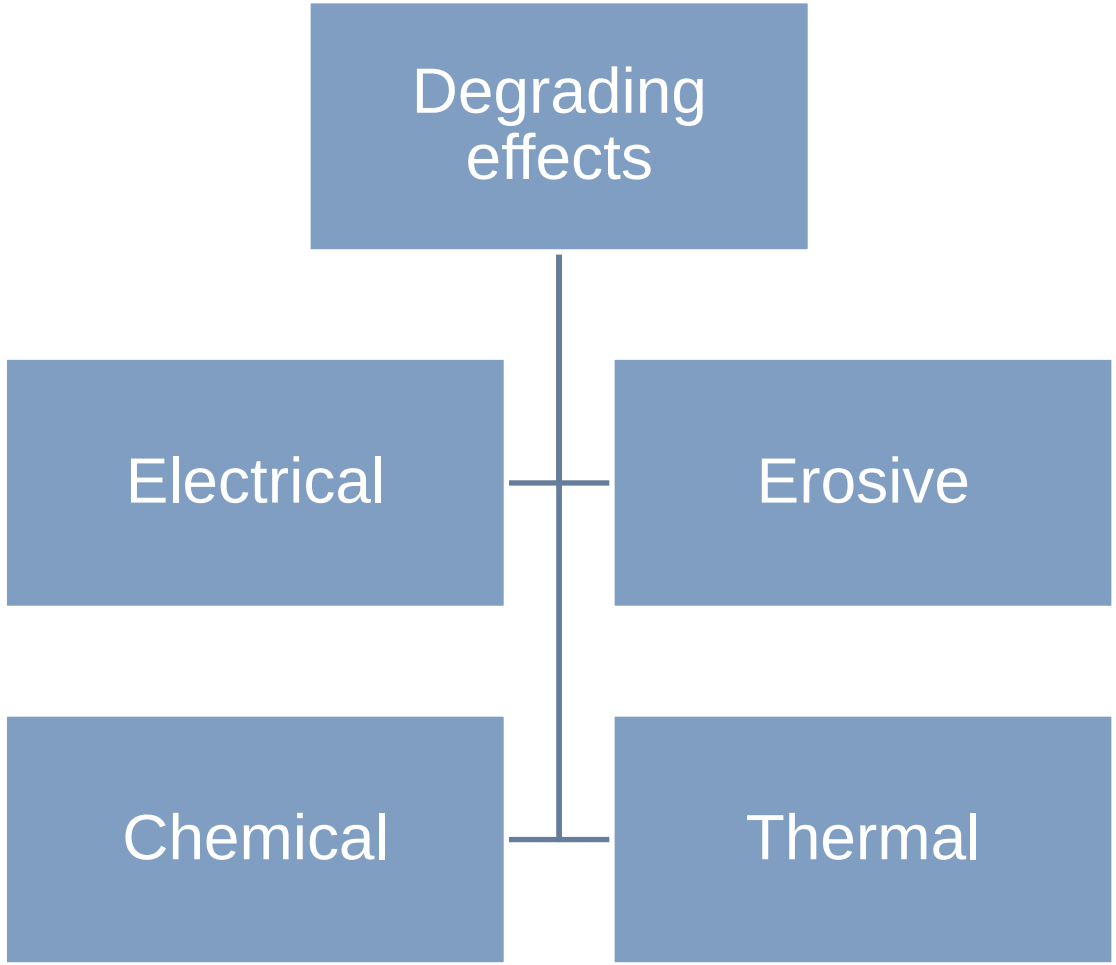
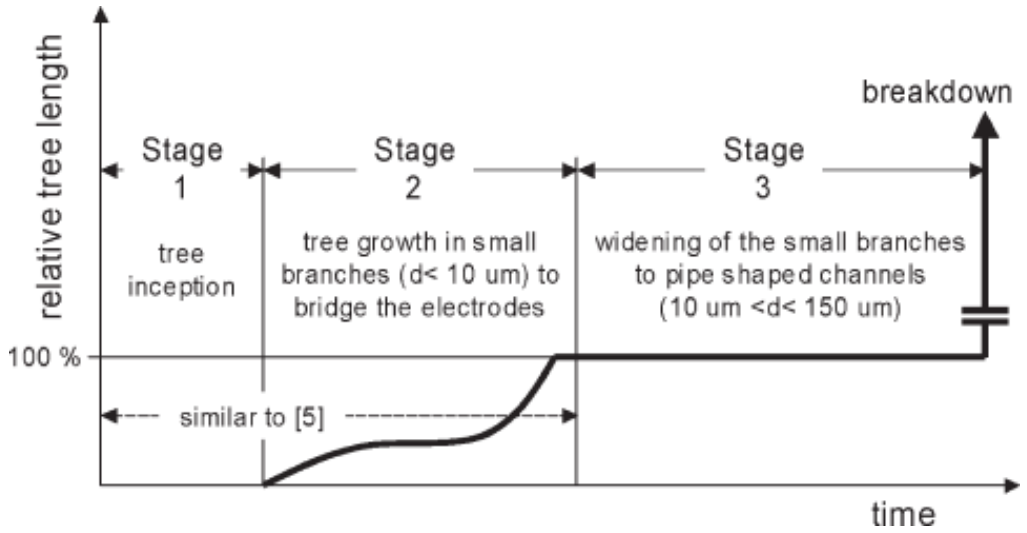
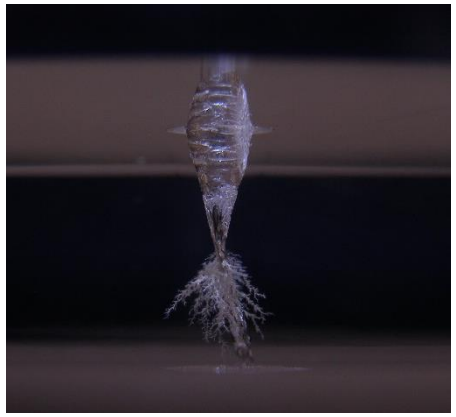
Degrading effects of electric fields - partial discharges



Degrading effects of electric fields - partial discharges

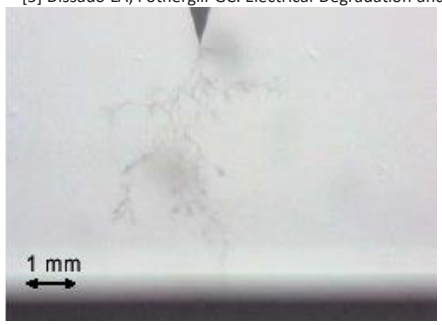
Treeing

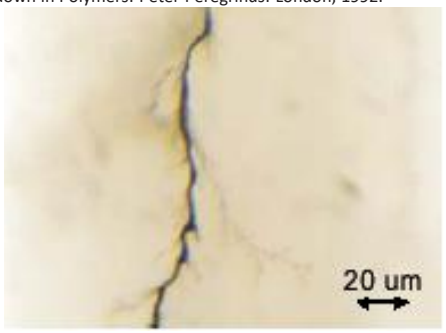


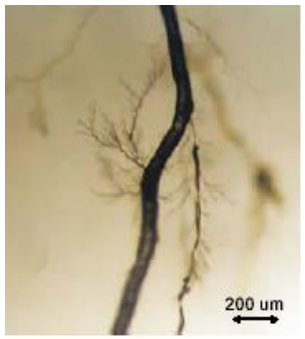


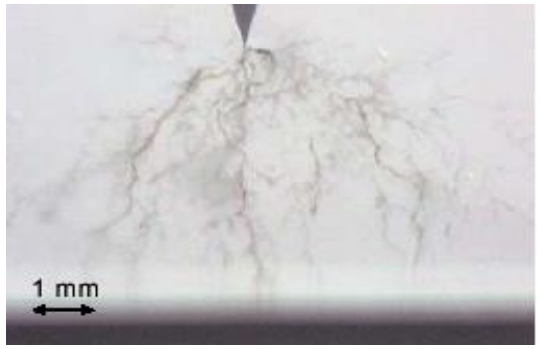
R. Vogelsang, B. Fruth, T.Farr, K. Frohlich;Detection of electrical tree propagation by partial discharge measurements, EUROPEAN TRANSACTIONS ON ELECTRICAL POWER, Euro. Trans. Electr. Power 2005; 15:271–284

[5] Dissado LA, Fothergill GC. Electrical Degradation and Breakdown in Polymers. Peter Peregrinus: London, 1992.









Accompanying phenomena of discharge activity

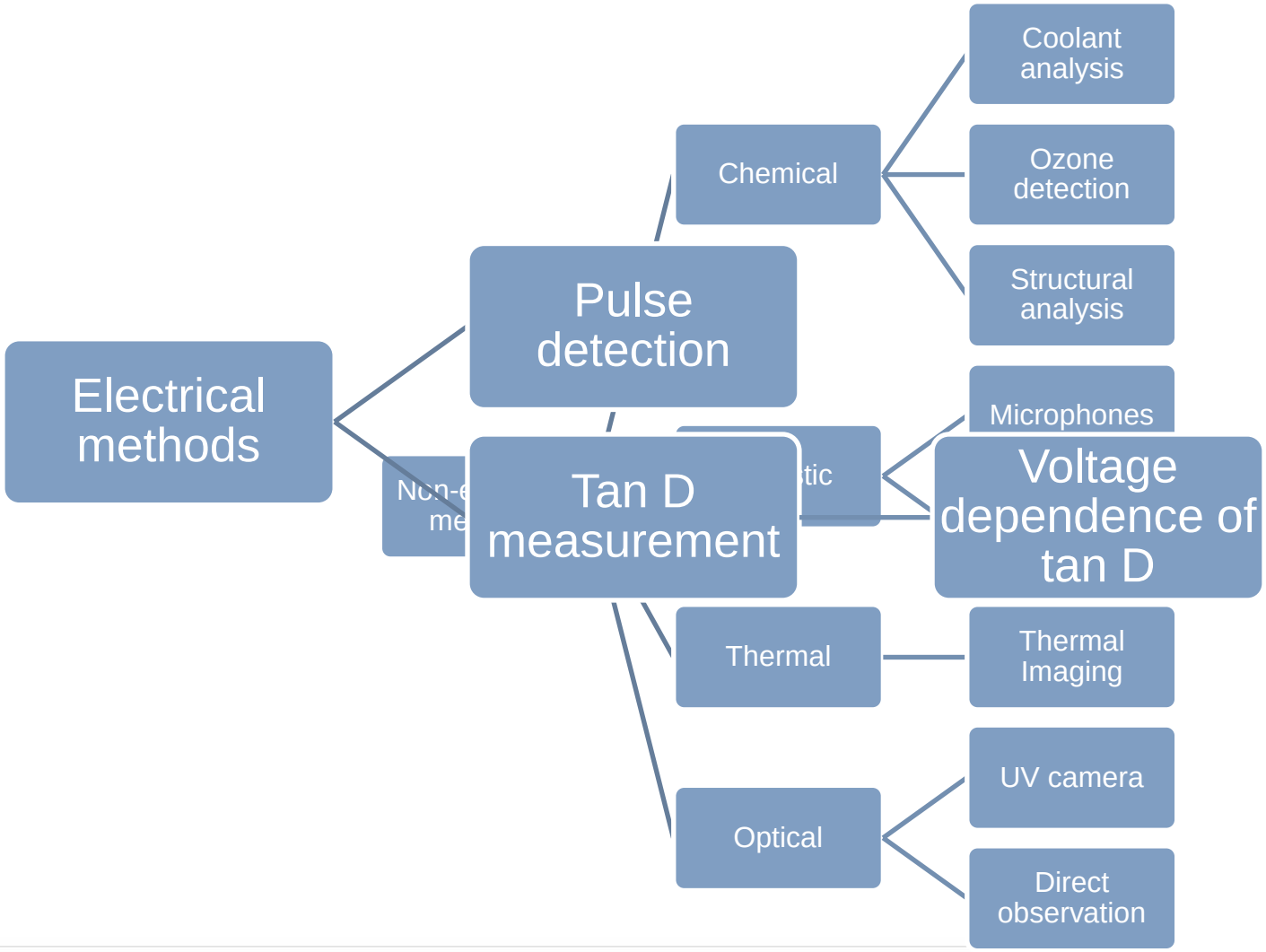
Electrical signals

- Increase in dielectric loss
- Current pulses in the ground terminal of the test object
- High frequency electromagnetic field

Non-electrical signals

- Chemical action of discharge products
- Light radiation in the visible and ultraviolet spectrum
- Thermal heating of the surroundings
- Sound waves in the audible and ultrasonic bands

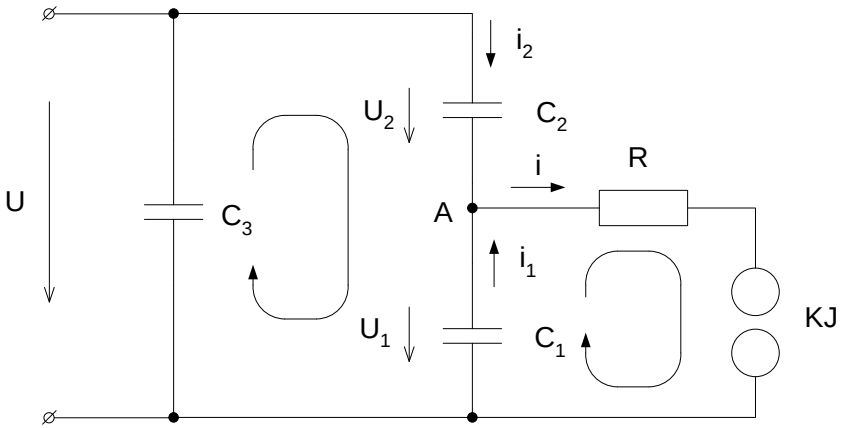
Partial discharge measuring methods

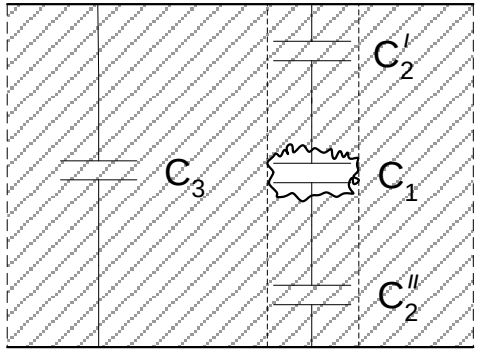


Theory of partial discharges

Gemant-Philippov model

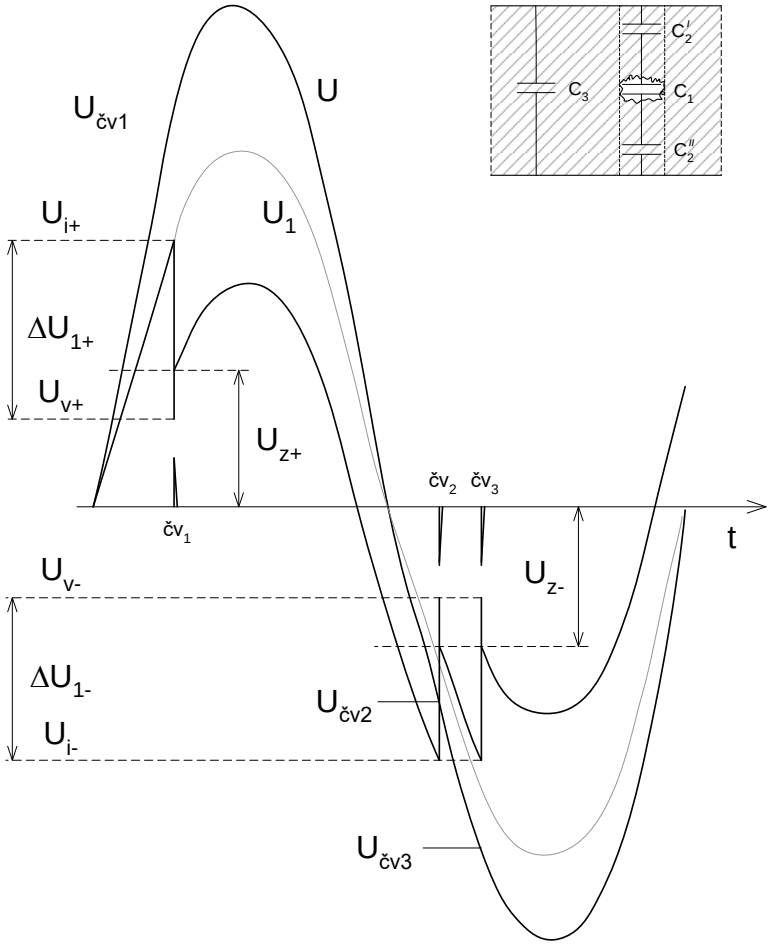
C1 - cavity capacity,
C2 - capacitance of the dielectric connected in series with the capacitance of the cavity $C_2 = C_2^{/} + C_2^{//}$
C3 - capacitance of the undamaged part of the dielectric,
R - resistance of the discharge channel,
KJ - spherical spark gap (its ignition represents a partial discharge).





Theory of partial discharges

Voltage waveform on the cavity



U - voltage applied to the terminals U = Um sin2pft,

U1 - voltage on the cavity U1 = U1m sin2pft,

Ui - immediate value of the ignition voltage of the cavity,

Uv - immediate value of the residual voltage (after discharge),

Uz - recovered voltage,

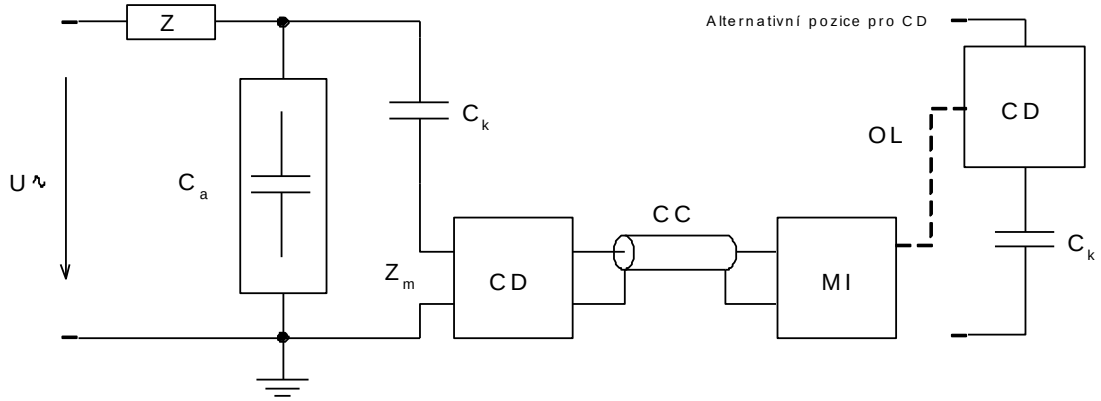
ΔU1 - voltage drop on the cavity due to partial discharge,

Učv - voltage on the sample at the moment of partial discharge

PD electrical measurement methods

Global method

Coupling device in series with coupling capacitor



Z- interference filter, barrier to discharge of the CT through the impedance of the power supply

Ca- object under test

Ck- coupling capacitor

Zm- sensing impedance

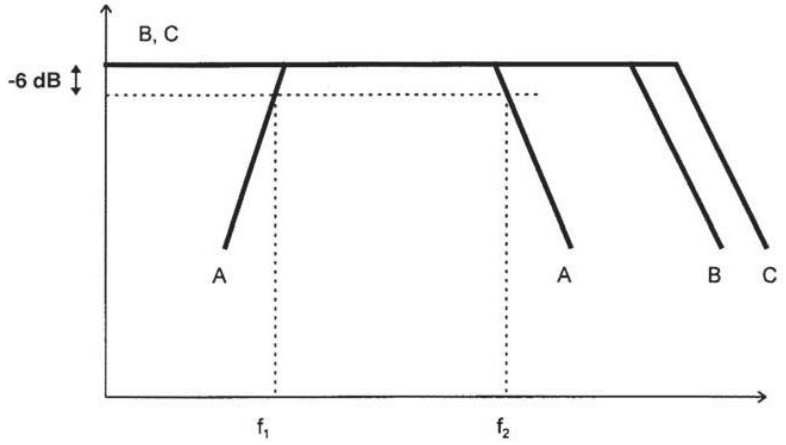
CD- coupling device

CC- coupling cable

MI- detector

OL- optical cable

PD electrical measurement methods



A bandpass of the measuring system
B amplitude frequency spectrum of the PD pulse
C amplitude frequency spectrum of calibration pulse
f_1 lower limit frequency
f_2 upper limit frequency

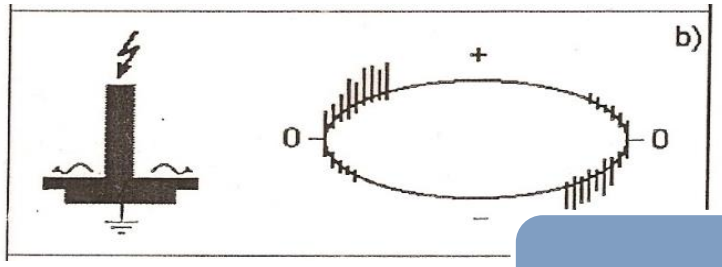
Correct relationship between amplitude and frequency to minimize integration errors for a wide-band system

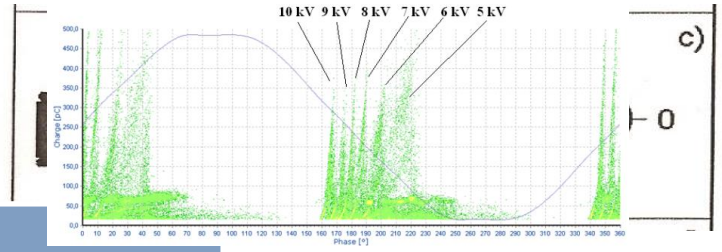
Wide-band PD instruments measuring system which is characterized by a **transfer impedance** $Z(f)$ having fixed values of the **lower and upper limit frequencies f_1 and f_2**, and adequate attenuation below f_1 and above f_2.

Recommended values for the significant frequency parameters f_1, f_2 and Δf are:

30 kHz $f_1 \leq 100$ kHz;
$f_2 \leq 1$ MHz;
100 kHz $\leq \Delta f \leq$ 900 kHz.

When data measured and acquired





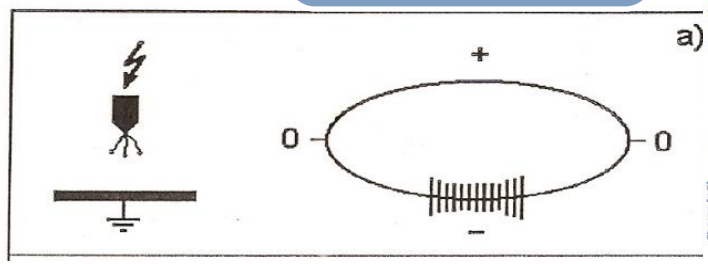
Surface discharge

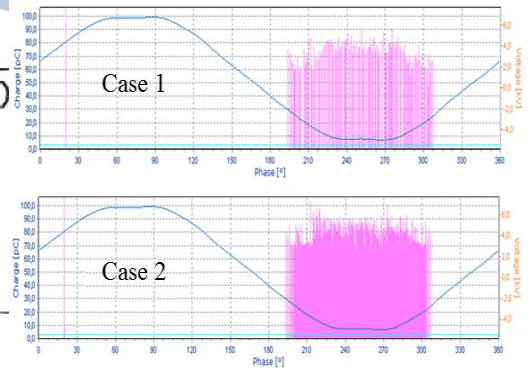
Internal discharge in the cavities

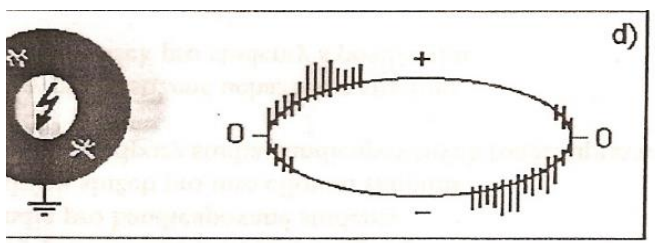
Corona discharge

PD

Breakthrough channels in solid insulation







CIGRE – Recognition of discharges

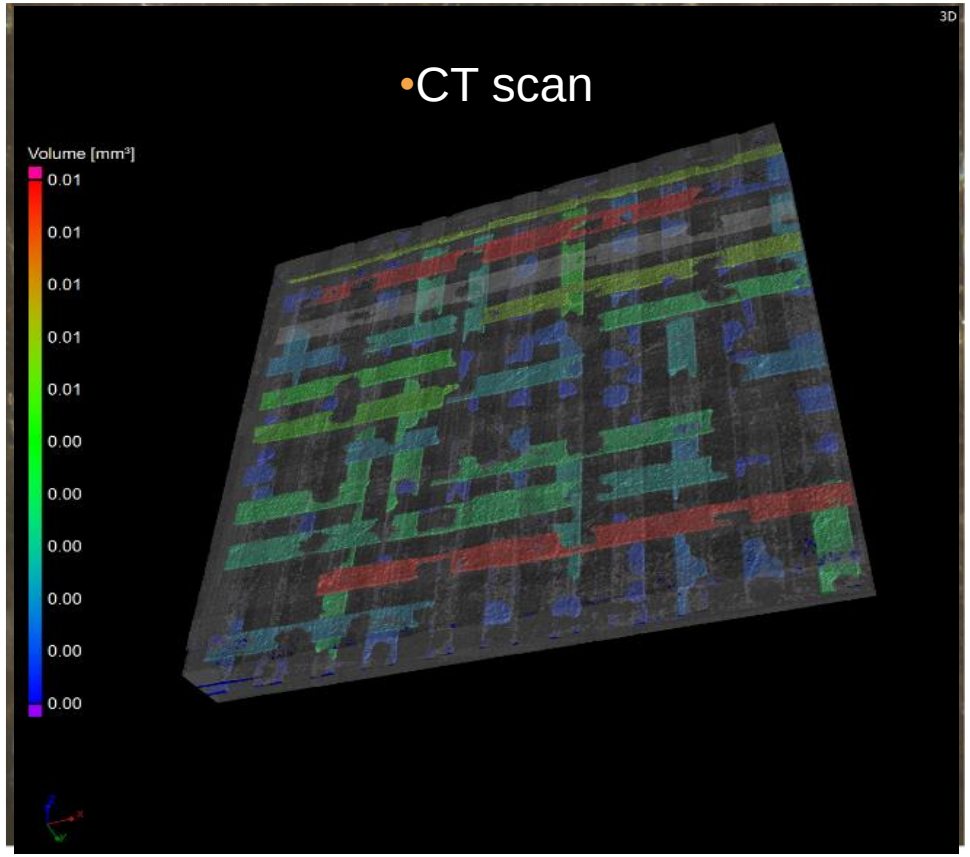
What is PD good for – example of use

What is PD good for – example of use

Typical HV dielectric material – generator insulation

- Glass fibres
- Mica paper
- Epoxy resin

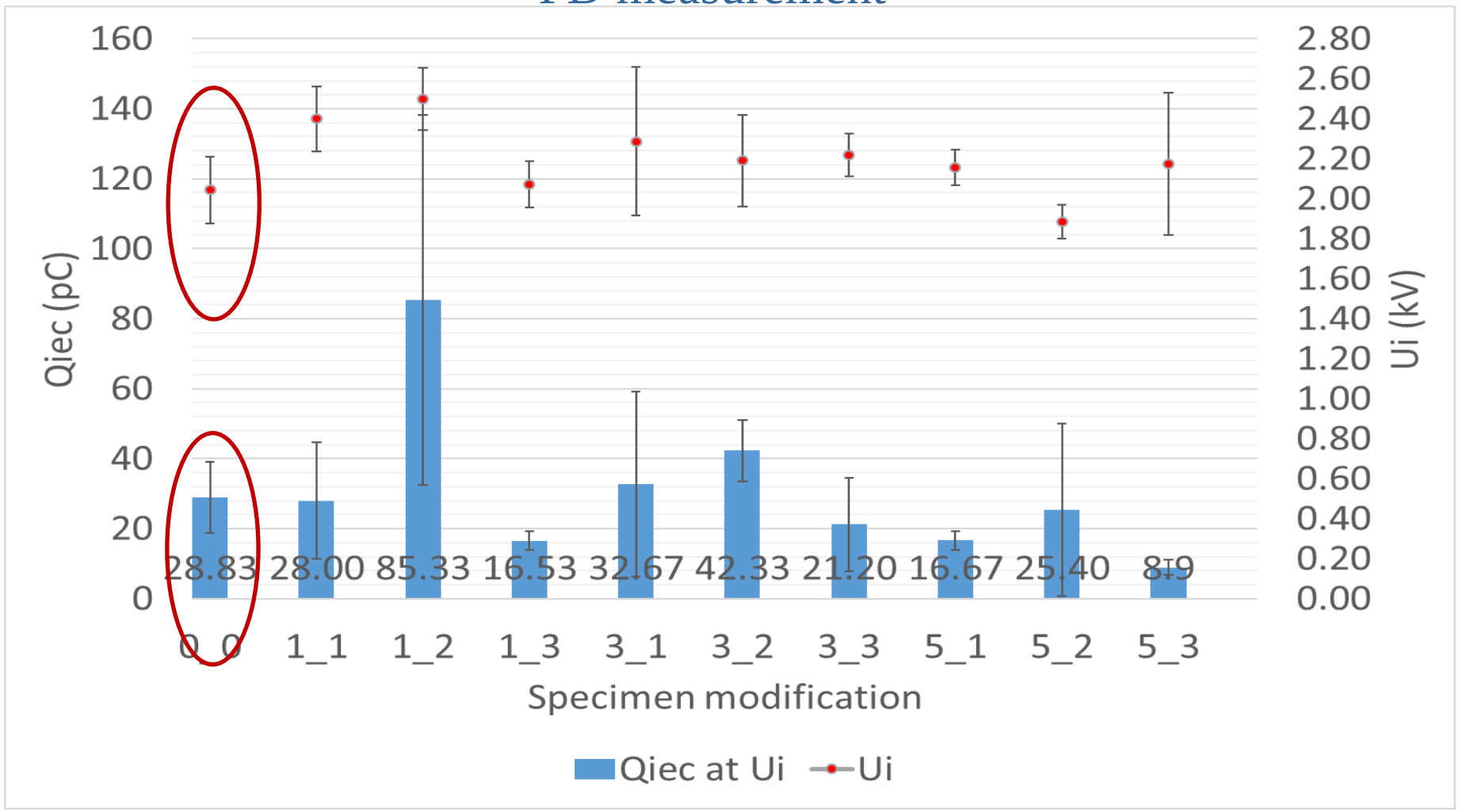
- Cured at pressure and temperature
- Full of voids
  - Danger for the material
  - Danger for whole device



[1] R. Polanský, P. Prosr, M. Zemanová, J. Pihera, T. Džugan, and J. Chvojka, "Electrospun nanofibres as a tool for controlling the gas bubble size distribution in fibre/thermoset-matrix composites," *Compos. Sci. Technol.*, vol. 163, no. February, pp. 96–104, 2018.
[2] J. Pihera, R. Polansky, M. Zemanova, P. Prosr, and J. Chvojka, "Partial discharges of nonwoven nanofibers composite," in *2016 IEEE Conference on Electrical Insulation and Dielectric Phenomena (CEIDP)*, 2016, pp. 183–186.

What is PD good for – example of use

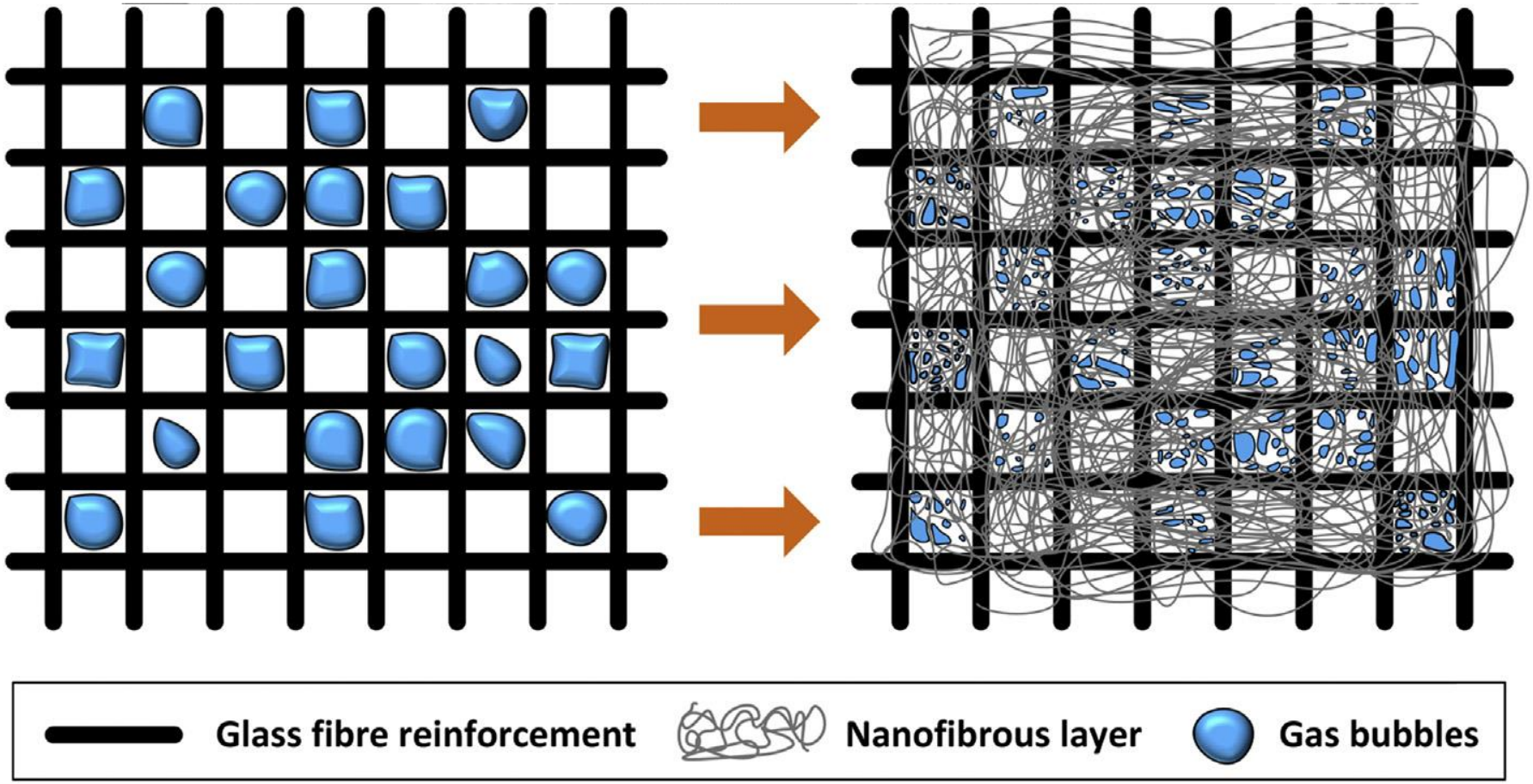
PD measurement



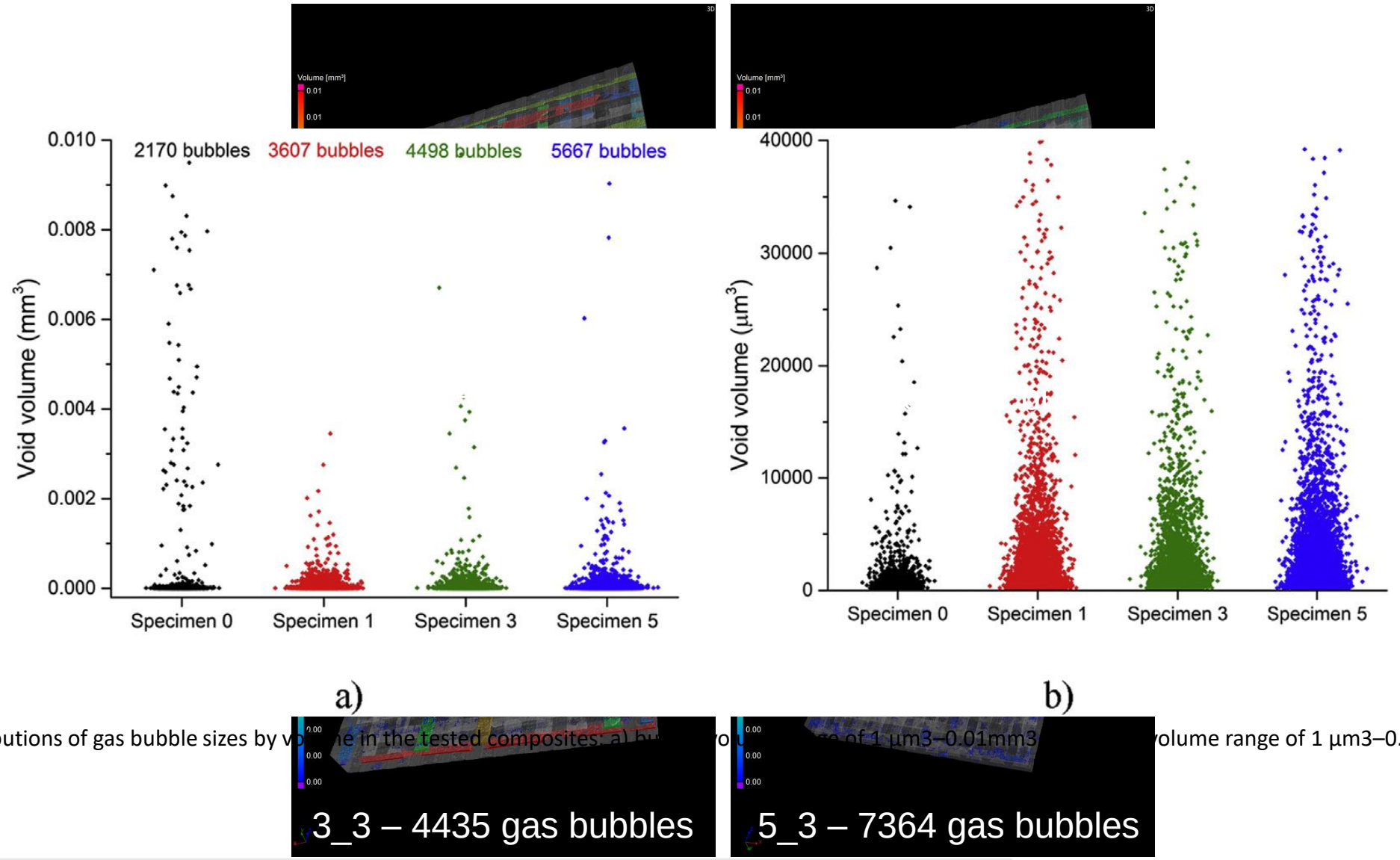
What is PD good for – example of use

PD suppression

- Using PA6 nanofibrous layers

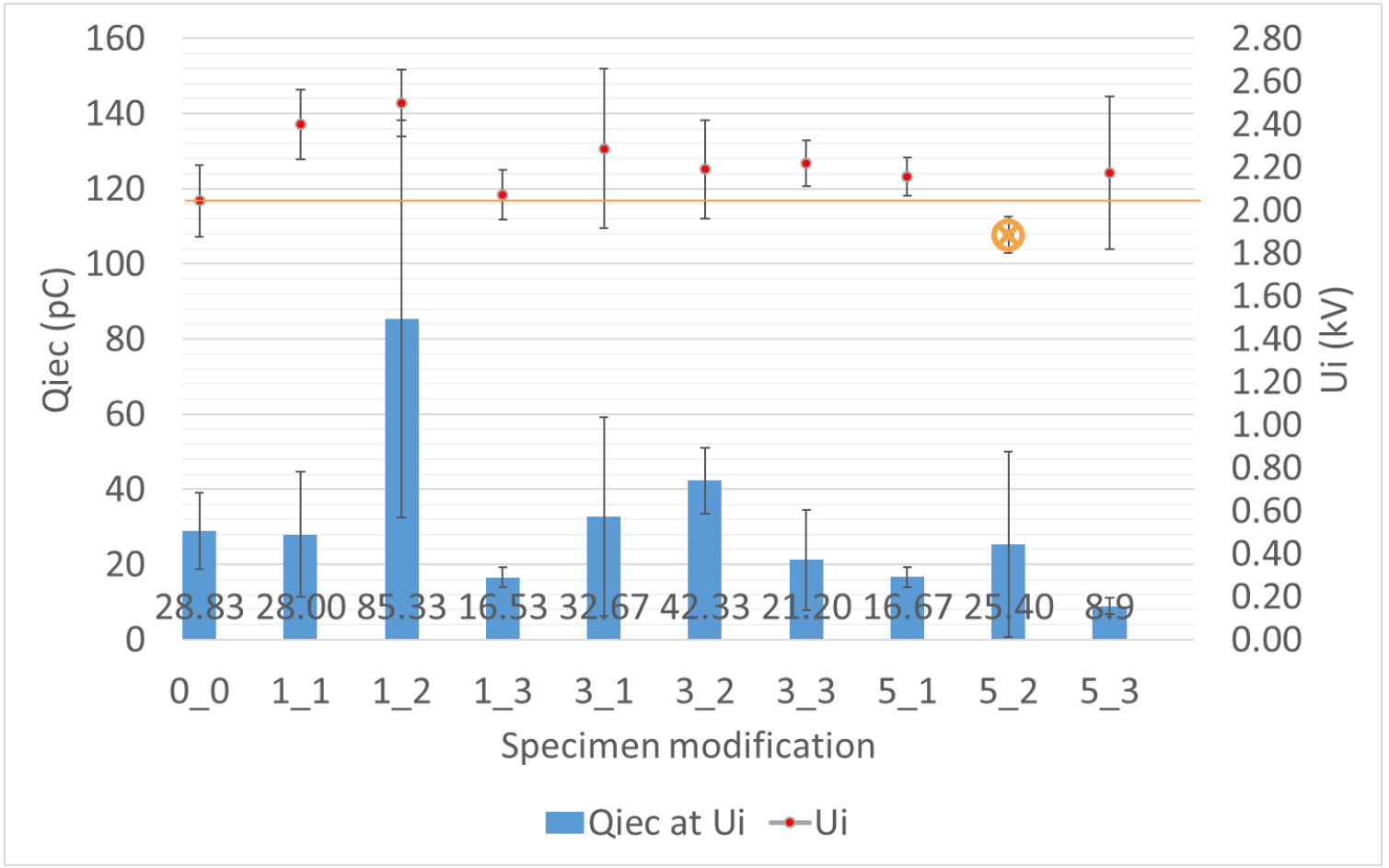


What CT and PD says to that

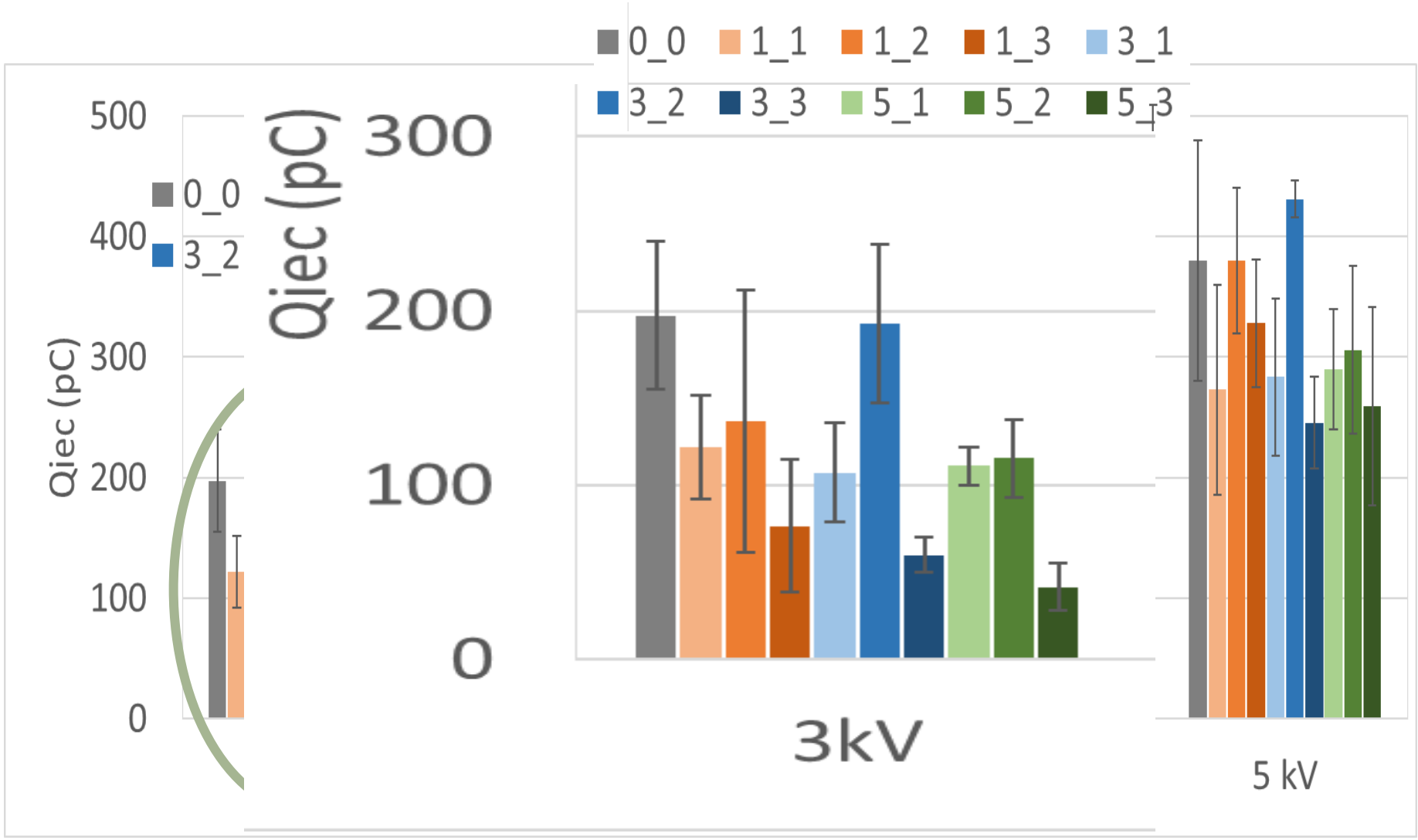


Distributions of gas bubble sizes by volume in the tested composites: a) bubble volume range of 1 µm3–0.01mm3, b) bubble volume range of 1 µm3–0.00004mm3.

What CT and PD says to that



What CT and PD says to that



Conclusions

- Curing monitoring is a powerful tool to monitor and control the curing process
- Curing monitoring is advance to all system proper conditions
- Could reduce the cost of curing process
- Partial discharges is sensitive method to verify the system homogeneity
- It is sensitive to small changes in material
- Possible to distinguish among PD type – PD source localization

... and what next

- PD Optical sensors
- PD sensors based on FBG optical fibres
- PD at DC voltage
- PD at pulse voltage

- Smart HV composite – internal build in diagnostics for electrical, thermal and mechanical properties (sensor on fibre, FBG, …, ???)

Thank you for your attention.

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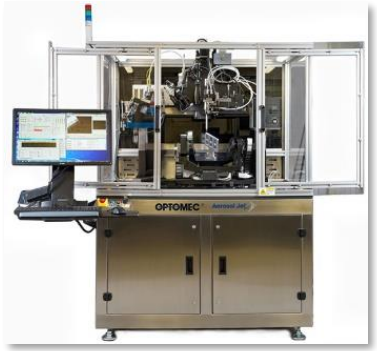
- +420 377 634 520
- +420 377 634 002

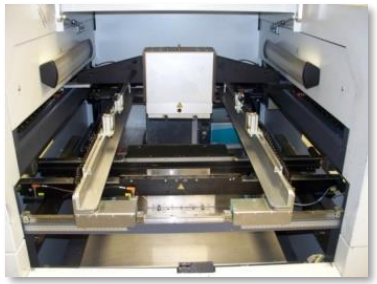
Printed electronics – technologies

Additive deposition technologies for Printed Electronics at RICE:

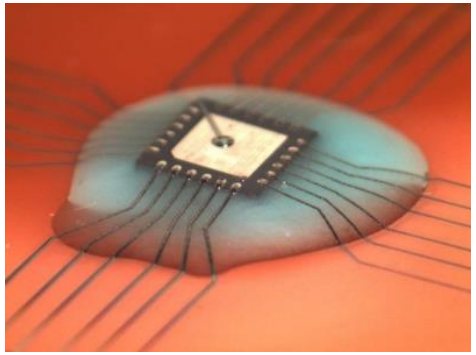
- Aerosol Jet Printing
- Screen Printing
- Spray coating



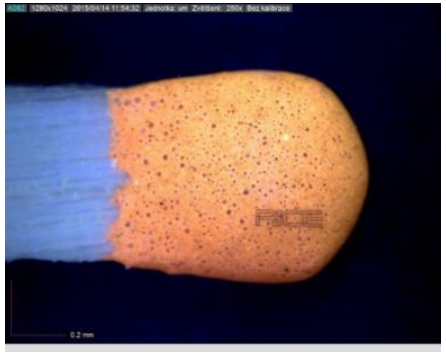
Optomec Aerosol Jet 300



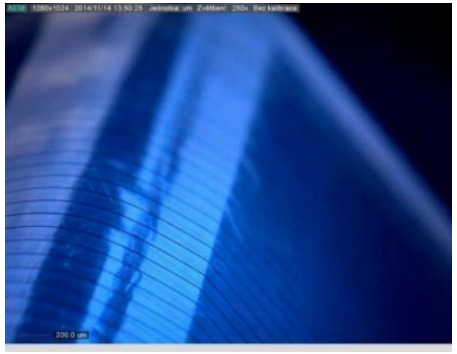
Ekra E2 Screen Printer



Printing of IC interconnections



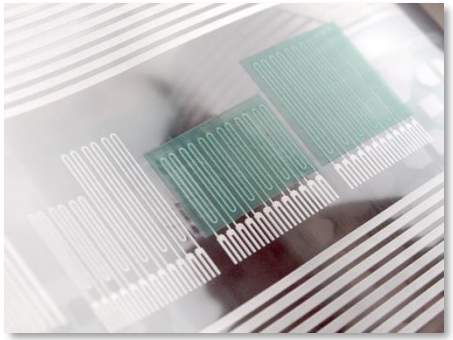
Precise functional printing (10µm)

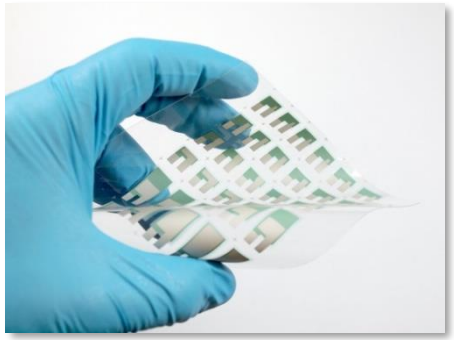


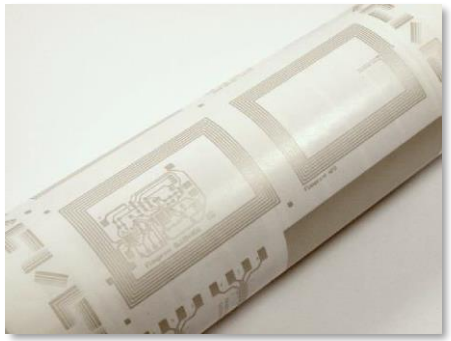
Printing on curved surfaces

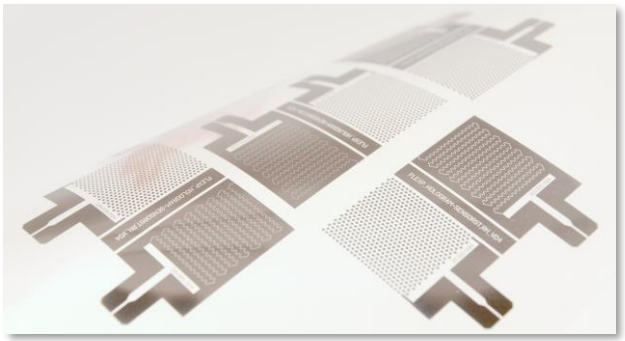
Printed electronics – functional blocks

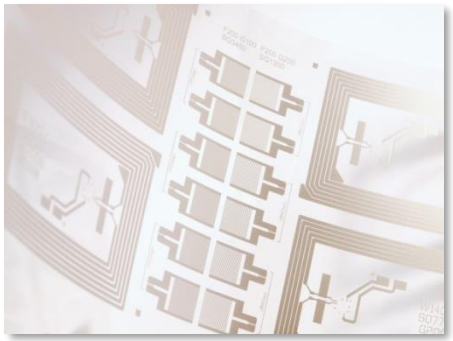
- **R&D in Printed electronics:**
  - **Components**
    - Passives – R, L, C
    - Actives - transistors
    - Antennas – HF, UHF
    - Sensors – T, RH, chemical
  - **System-on-Foil**
    - Hybrid RFID tags (T+RH sensors)
    - ID systems on metal holograms



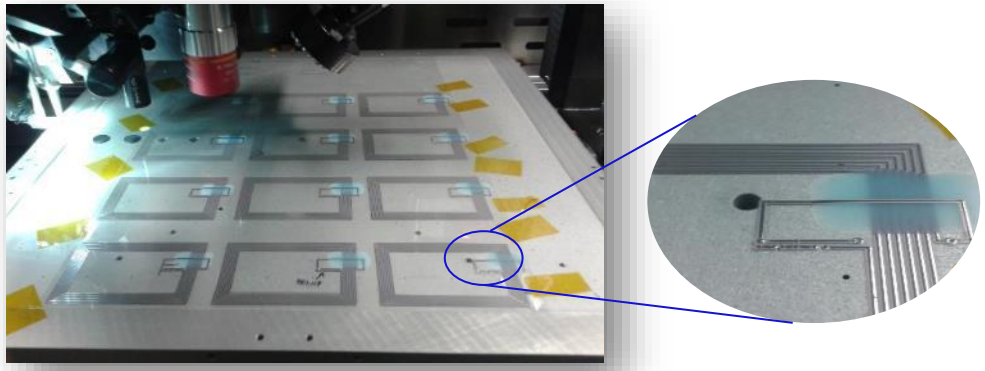




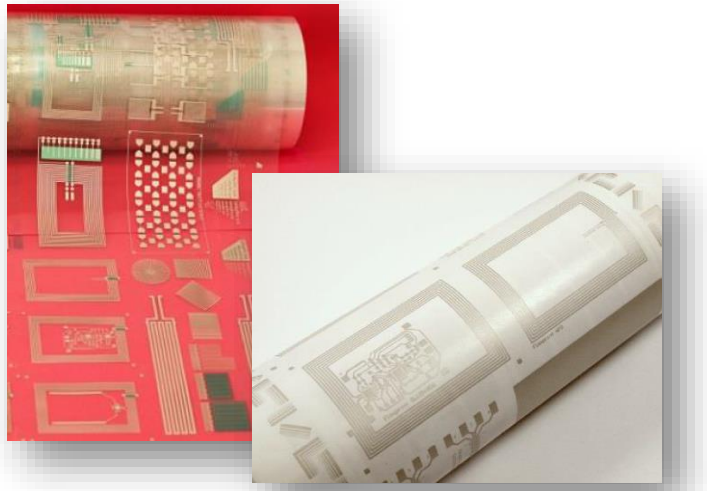




Flexible antennas

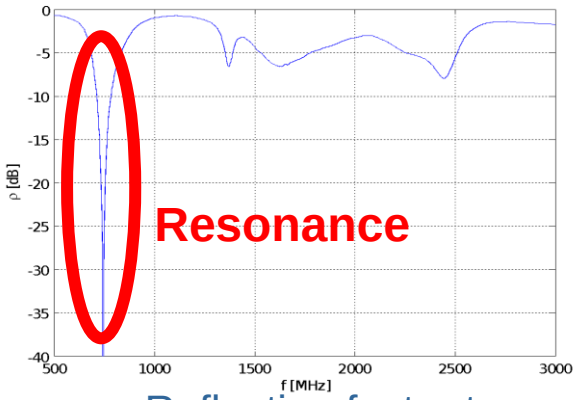


Aerosol Jet printed RFID antenna.



Antennas printed by R2R flexography on foil and paper.
(cooperation: UPce, OTK)

868 MHz antenna printed on textile substrate.



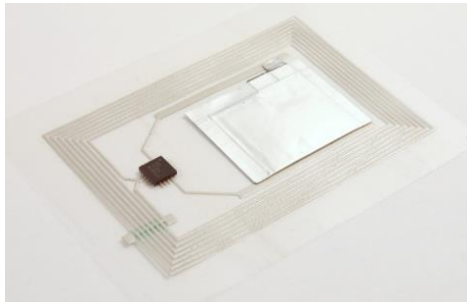
Reflection factor to frequency characteristics.

Embroidered antennas.

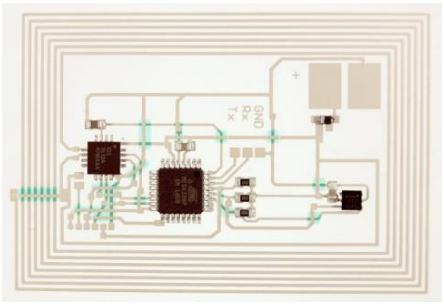
Hybrid electronic systems-on-foil

Hybrid systems printed on foil

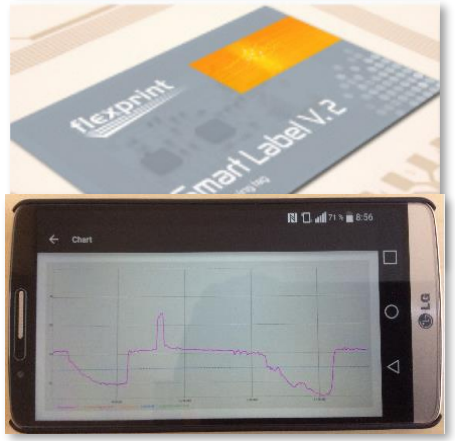
- Hybrid = print what you are able to, assemble what you have to.
- Flexible NFC sensor tags for smart labels, smart packaging, logistics and IoT.
- Including data logging, Android application for data visualization a cloud data management system (Firebase).
- Smart labels for:
  a) temperature logging
  b) temperature and relative humidity logging.



Smart label for temperature logging



Smart label for combined logging of temperature and relative humidity

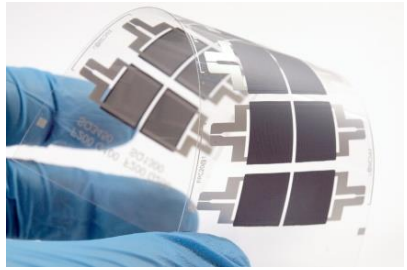


Smartphone application for label control and data transfer to cloud storage (NFC, Google Firebase)

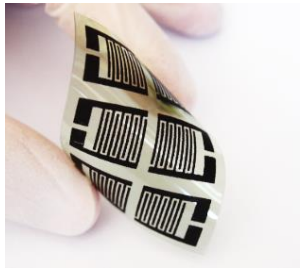
Printed sensors

Development of printed sensors:

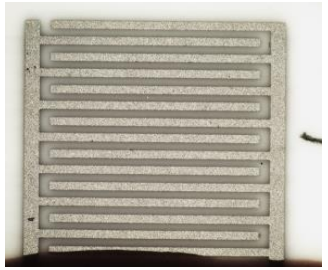
- Electrochemical and chemoresistive planar gas sensors
- Sensors based on carbon nanostructures
- Temperature and humidity sensors
- Thread-like sensors



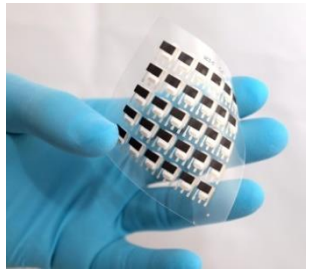
Temperature sensor
(Flexible NTC thermistor)



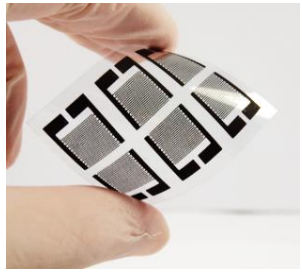
Ammonia sensor
(Chemoresitive)



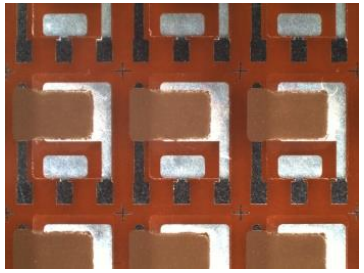
Amonia sensor
(based on CNTs printed by AJP)



Nitrogen oxide sensor
(Electrochemical)



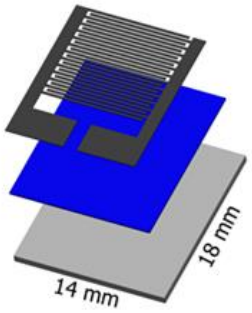
Humidity sensor
(Chemoresitive)



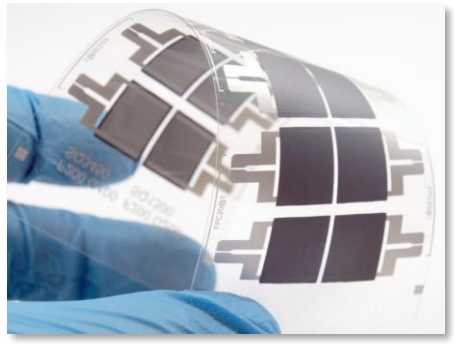
Ethylene sensor
(Electrochemical)

Resistive sensors

Flexible NTC thermistor

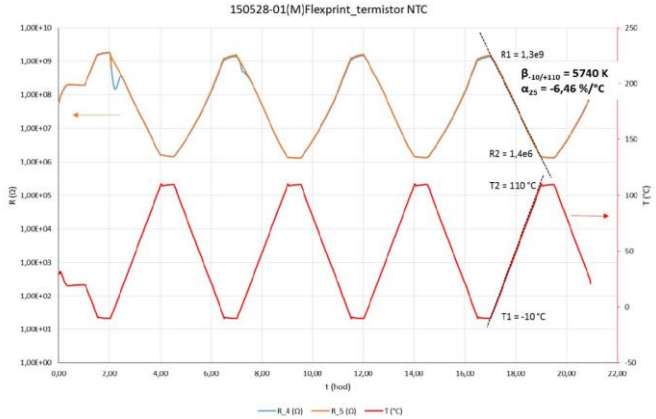


Sensor layout

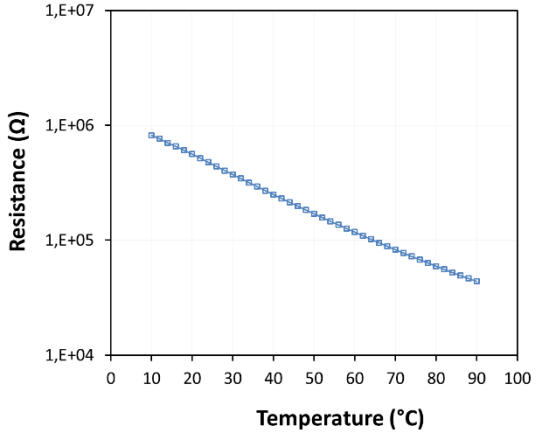


Sheet of temperature sensors

- Interdigital electrodes (200 µm - gap/finger)
- NTC inorganic layer
- Tested range -10 – 110 °C
- High sensitivity and stability during temperature cycling.



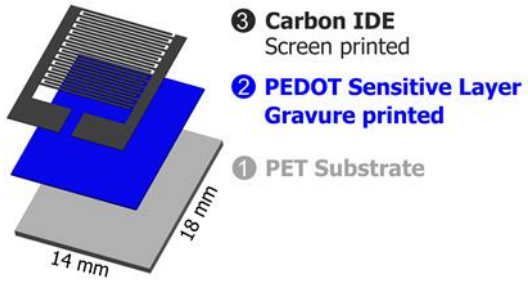
Thermistor response to temperature cycling



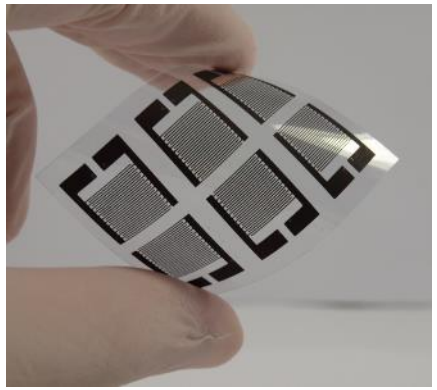
Calibration curve

Chemoresistive sensors

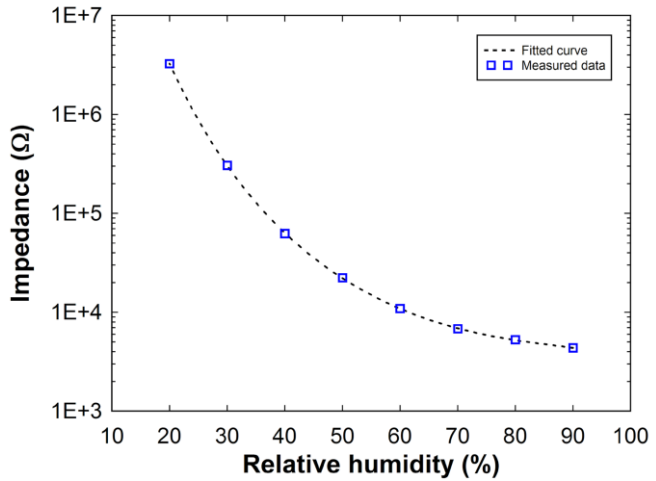
Humidity sensor



Sensor layout



Sheet of humidity sensors

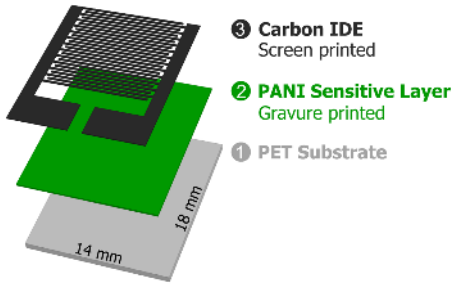


Sensor response to relative humidity, range of 20-80% RH (1 step = 10% RH)

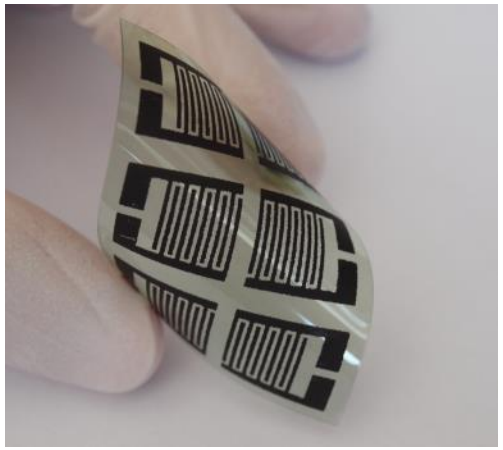
- Interdigital electrodes (200 µm - gap/finger)
- PEDOT:PSS sensitive layer
- Tested range 20 – 80% RH

Chemoresistive sensors

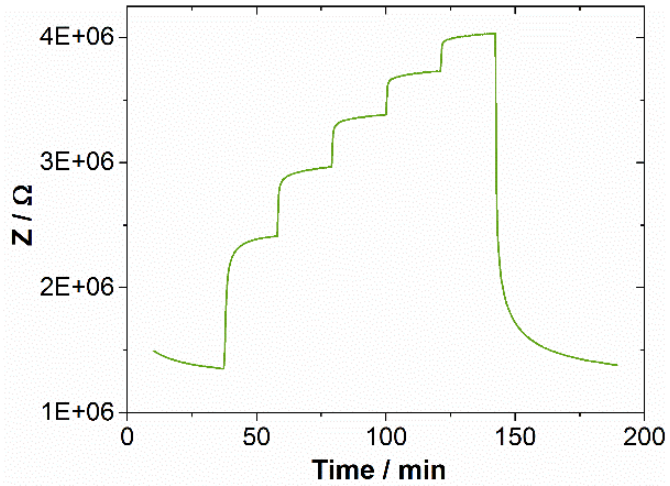
Ammonia sensor



Sensor layout



Sheet of ammonia sensors

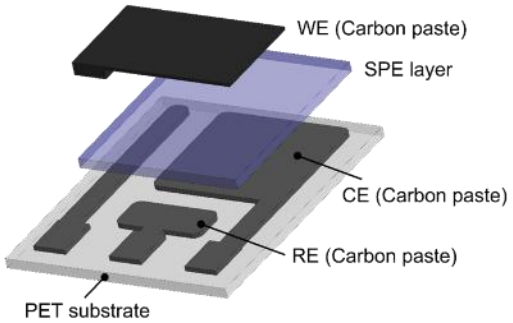


Sensor response to stepwise increases from 0 to 50 ppm NH_3 (1 step = 10 ppm NH_3)

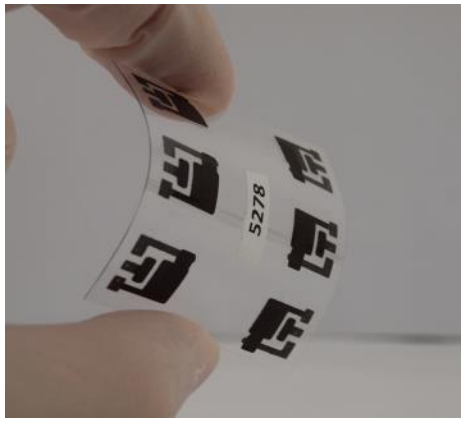
- Interdigital electrodes (500 µm - gap/finger)
- PANI sensitive layer based on organic colloids
- Tested range 0 – 50 ppm

Electrochemical sensors

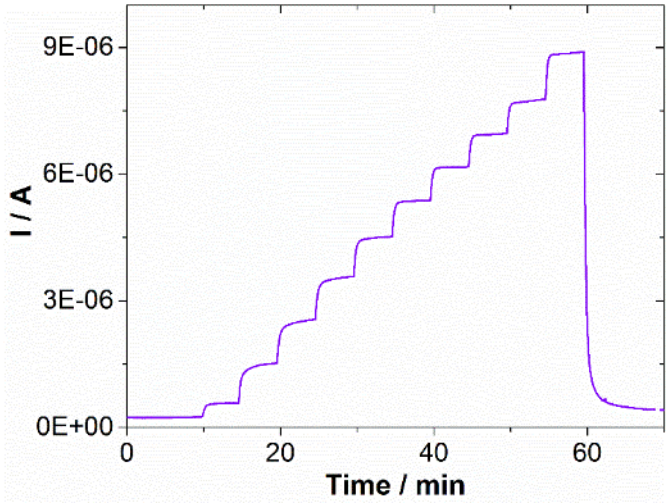
Nitrogen dioxide sensor



Sensor layout



Sheet of nitrogen dioxide sensors



Sensor response to stepwise increases in NO_2 concentrations: 1, 3, 5, 7, 9, 11, 13, 15, 17 and 20 ppm NO_2

- Semi-planar, three electrode topology
- Solid polymer electrolyte
- Tested range 0 – 20 ppm

Main partners

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