

Impedance Spectroscopy

Non-destructive Analyzes of Electronics Encapsulations

Sächsischer Arbeitskreis Elektronik-Technologie

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Power electronics

Definition and application

Lifetime > 20 years

Power electronics: »Transformation of electrical energy by using electronic components.«



- Power conversion for green energy
- Wide application range (kW – MW)
- Application temperature (-55 – 175 °C)
- Harshest environmental conditions

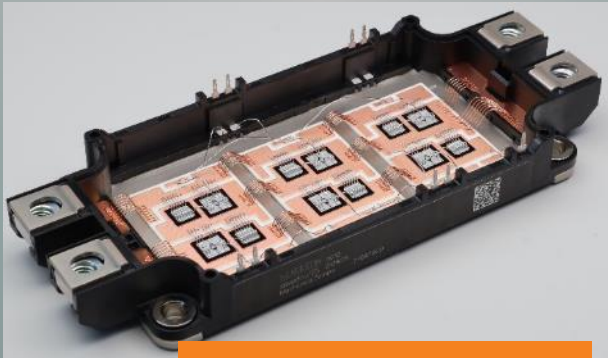
components

- Rectifier (AC/DC converter)
- Inverter (DC/AC converter)
- DC/DC converter (ΔU)
- AC/AC converter (ΔU and Δf)

Power electronics

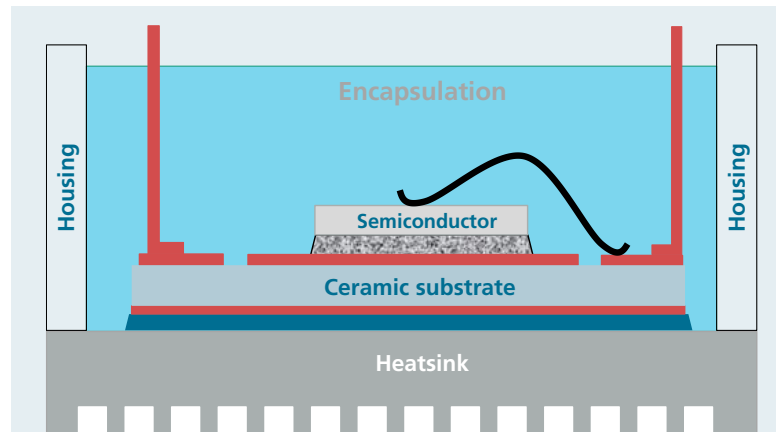
Encapsulation

Silicon



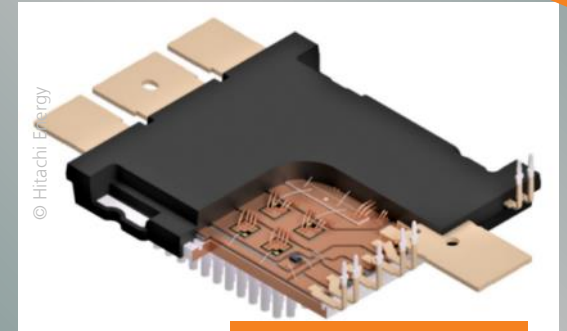
Standard IGBT module

Soft encapsulation (potting)

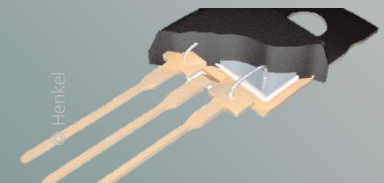


Polymer based layer in contact to metals

SiC



Hitachi RoadPak



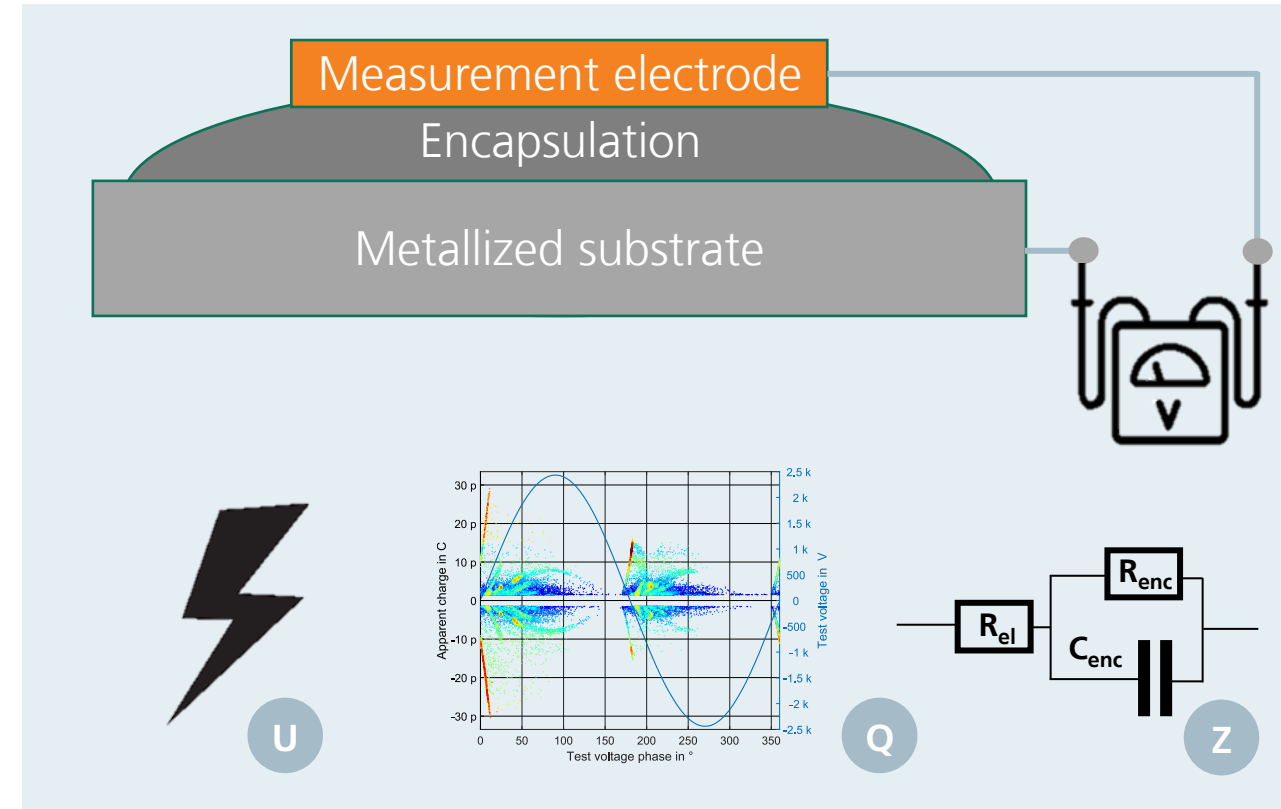
Molding of discrete components

Hard encapsulation (molding)

Encapsulation materials

Electrical characterization

- **Dielectric strength measurement (DT):**
 - Electrical breakdown voltage
- **Partial discharge measurement ("NDT"):**
 - Detection of electrical charges below breakdown
 - Correlation with material structure and failures
- **(Electrochemical) Impedance Spectroscopy (NDT):**
 - Impedance measurement of the material / system
 - Correlation to material structure and failures
 - Detection of material changes



Encapsulation materials

Electrical impedance basics

Electrical impedance: »Relation between voltage and current flow in dependency of the frequency.«

$$Z(f) = \frac{U(f)}{I(f)}$$

■ Resistance



$$Z_R = R$$

Material parameter

■ Capacitance

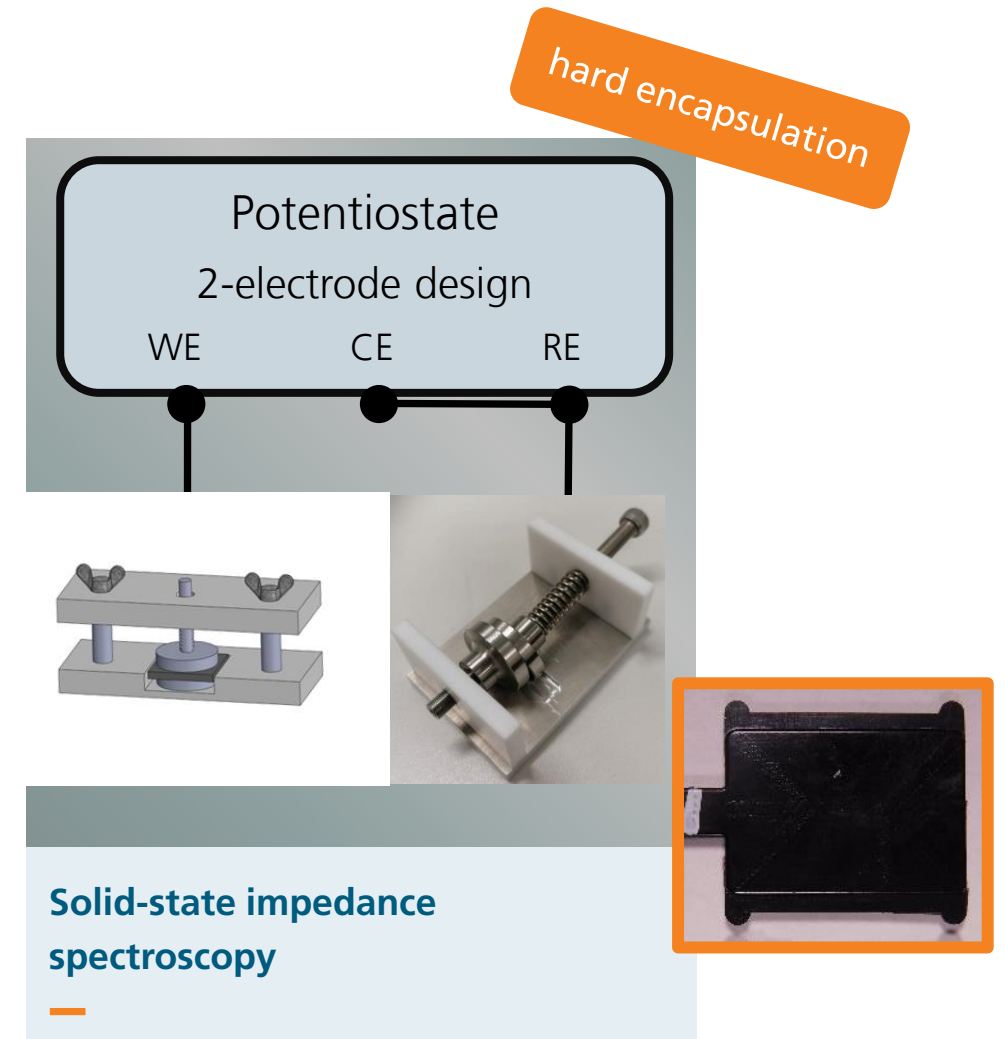
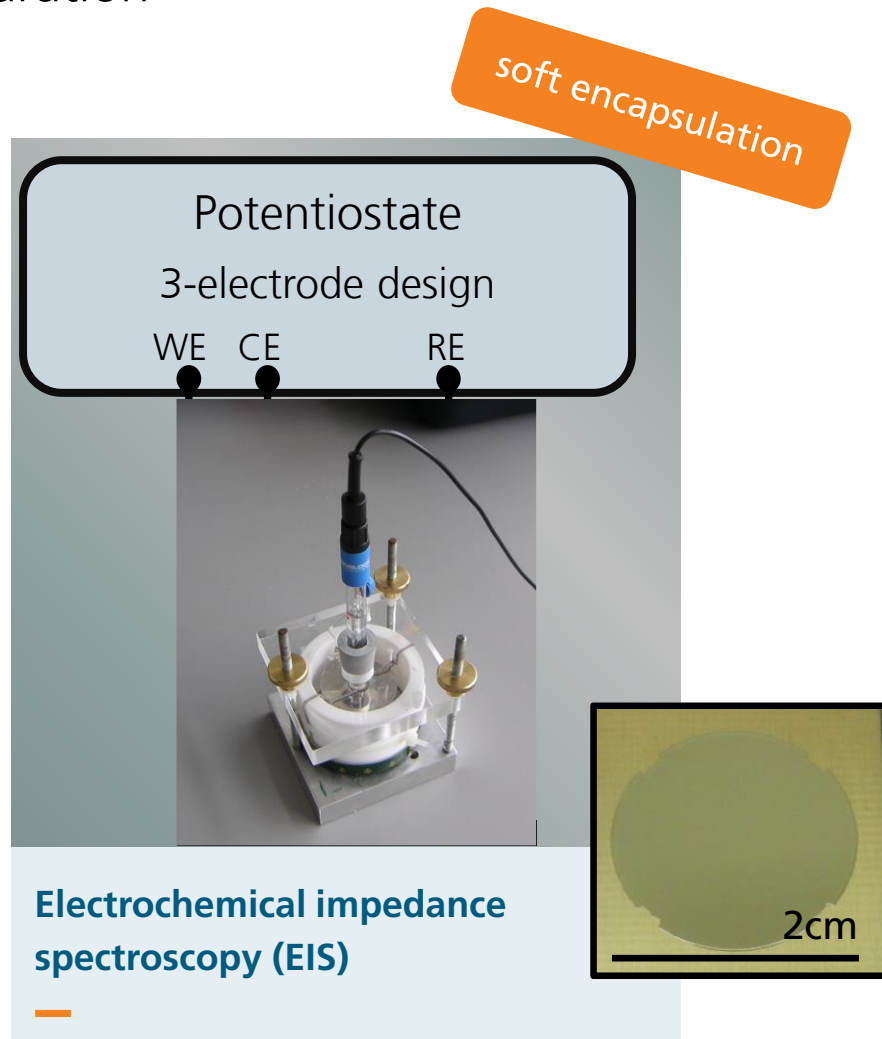


$$Z_C = -i \frac{1}{2\pi f \cdot C}$$

$$C = \varepsilon_0 \varepsilon_r \cdot \frac{A}{d}$$

Impedance spectroscopy

Sample preparation





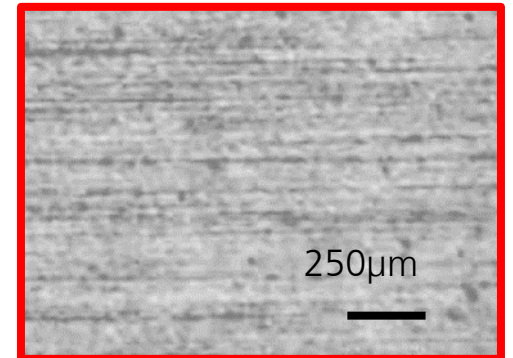
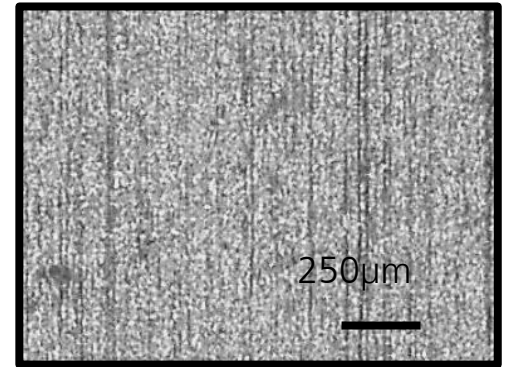
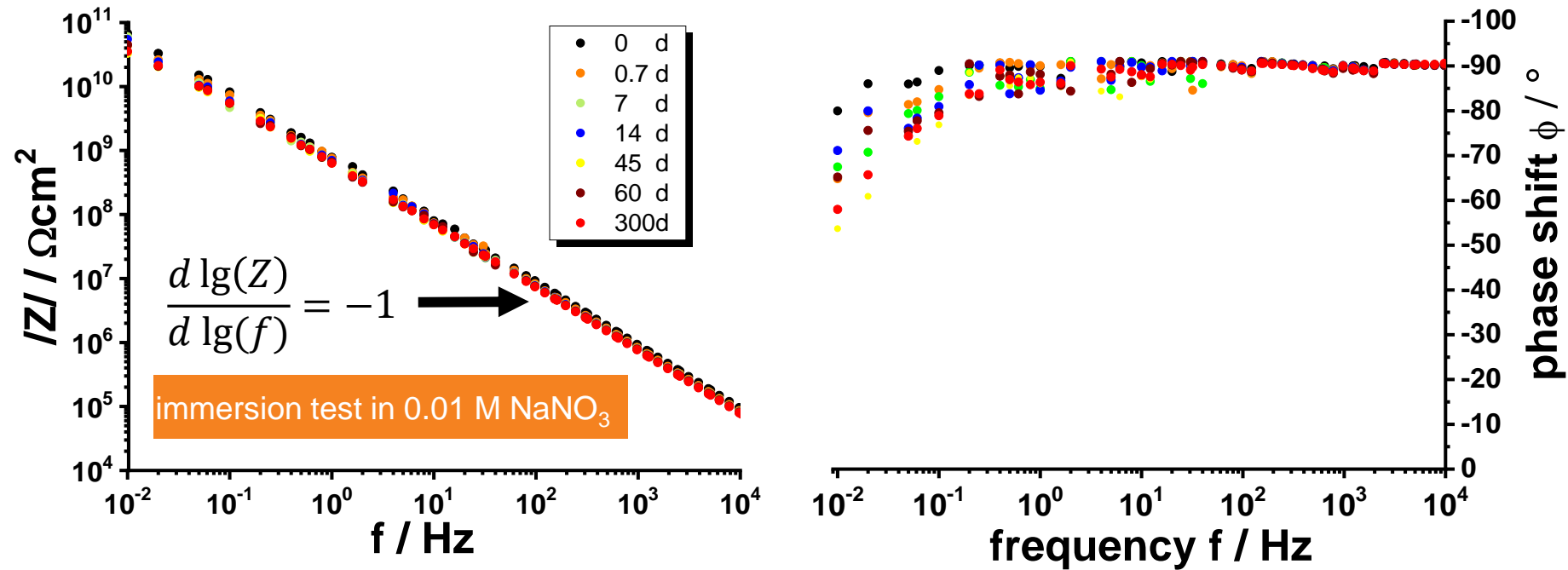
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Impedance spectroscopy on soft encapsulations

Electrochemical impedance spectroscopy

EIS after immersion test

Defect free application

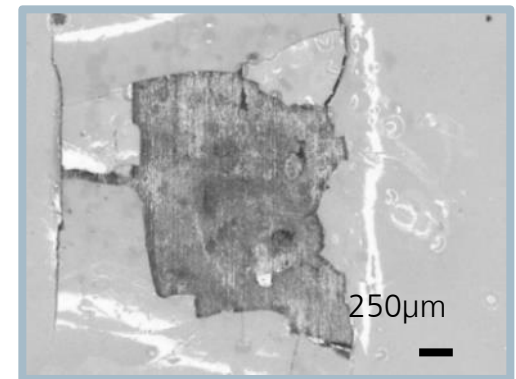
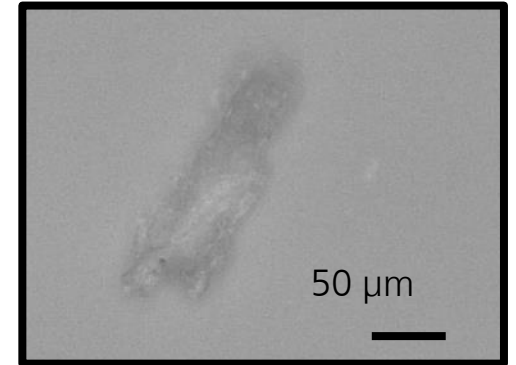
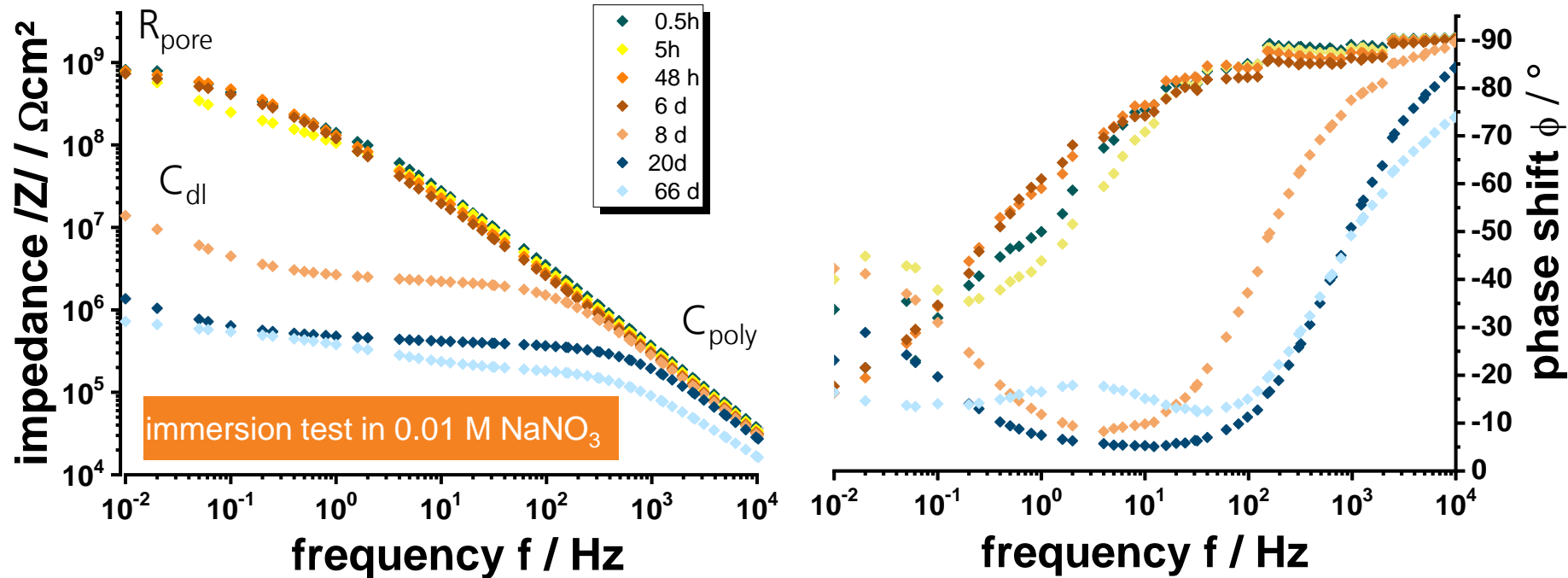


Immersion test of defect free encapsulation: »No defects observable«

Electrochemical impedance spectroscopy

Measurement results – defect area influence

Pores and defects



$$V_{\text{cap}} = 5 \text{ Vol. \% @ } 7h$$

$$A_{\text{del}} = \frac{C_{\text{dl}}^t}{C_{\text{dl}}^{\text{theor}}} \cdot 100\%$$

$$A_{\text{del}}^{6d} < 0.01 \%$$

$$A_{\text{del}}^{20d} \approx 7 \%$$



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Impedance spectroscopy on hard encapsulations

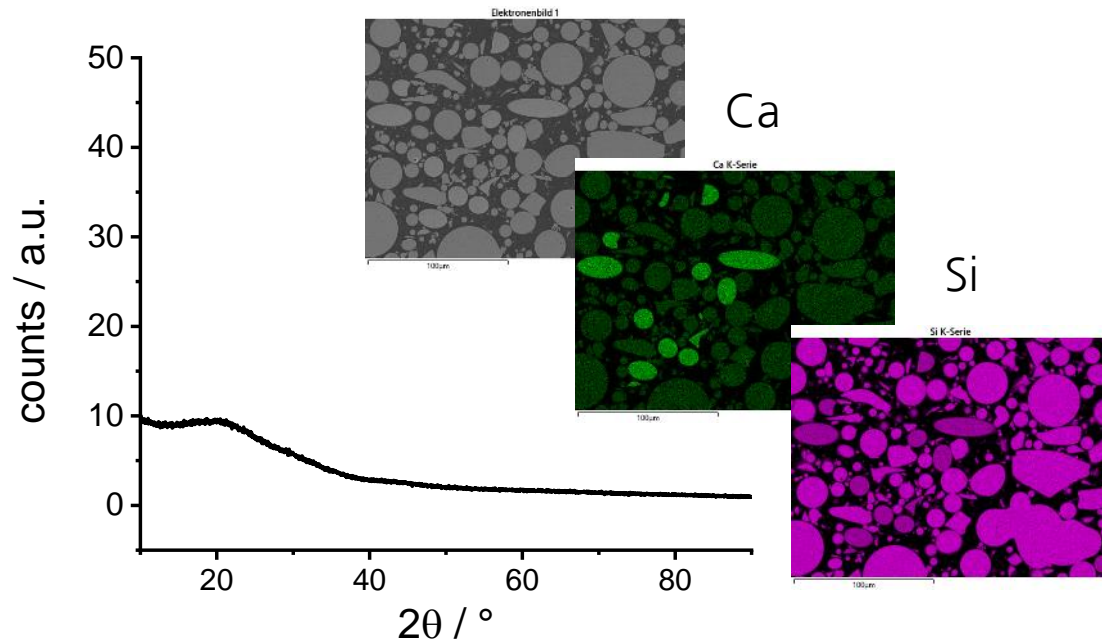
Solid-state impedance spectroscopy

Theoretical approach – challenges

EMC ≠ EMC

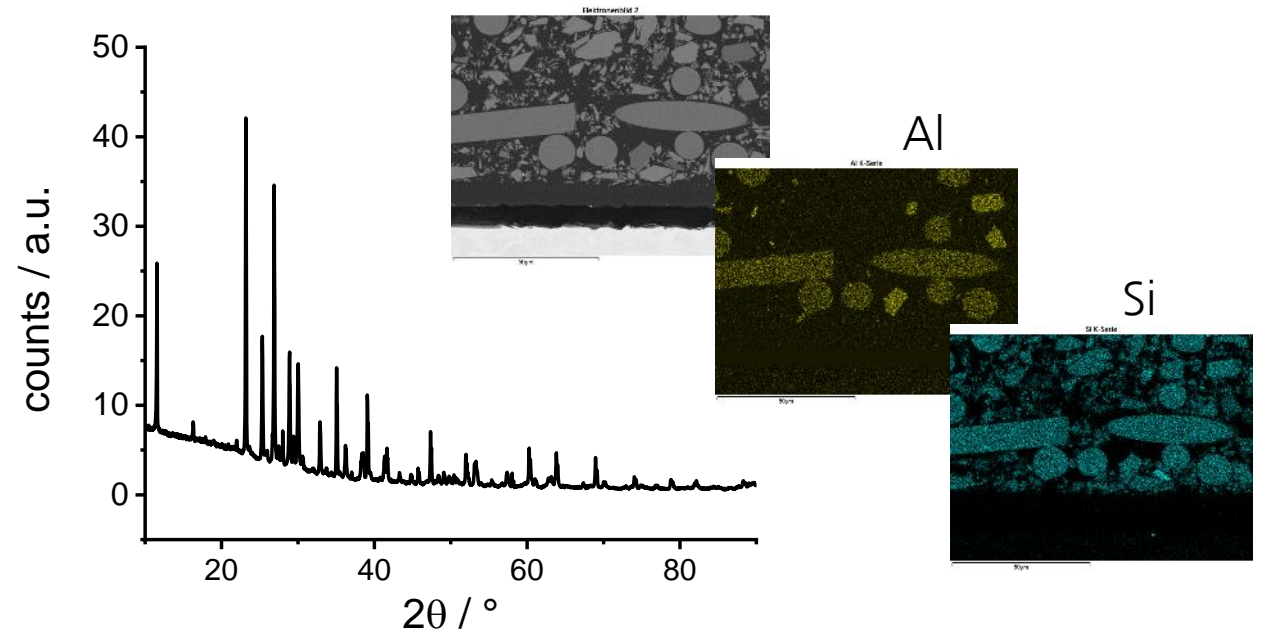
- **EMA A**
(filled with inorganic resin carriers)

- Resistivity: 10^{14} - $10^{16} \Omega \text{ cm}$
- Permittivity: 5-7 (100 Hz)



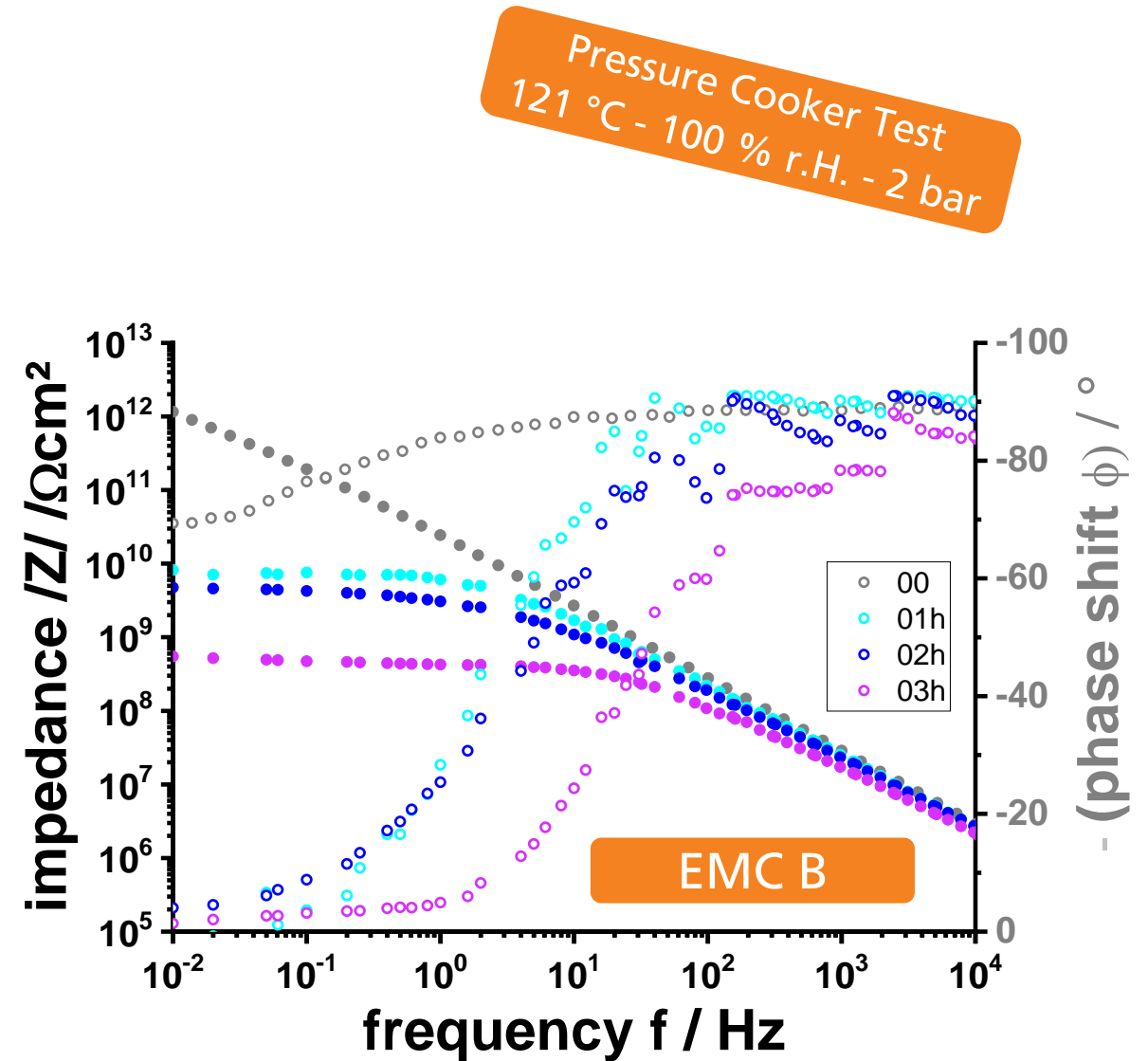
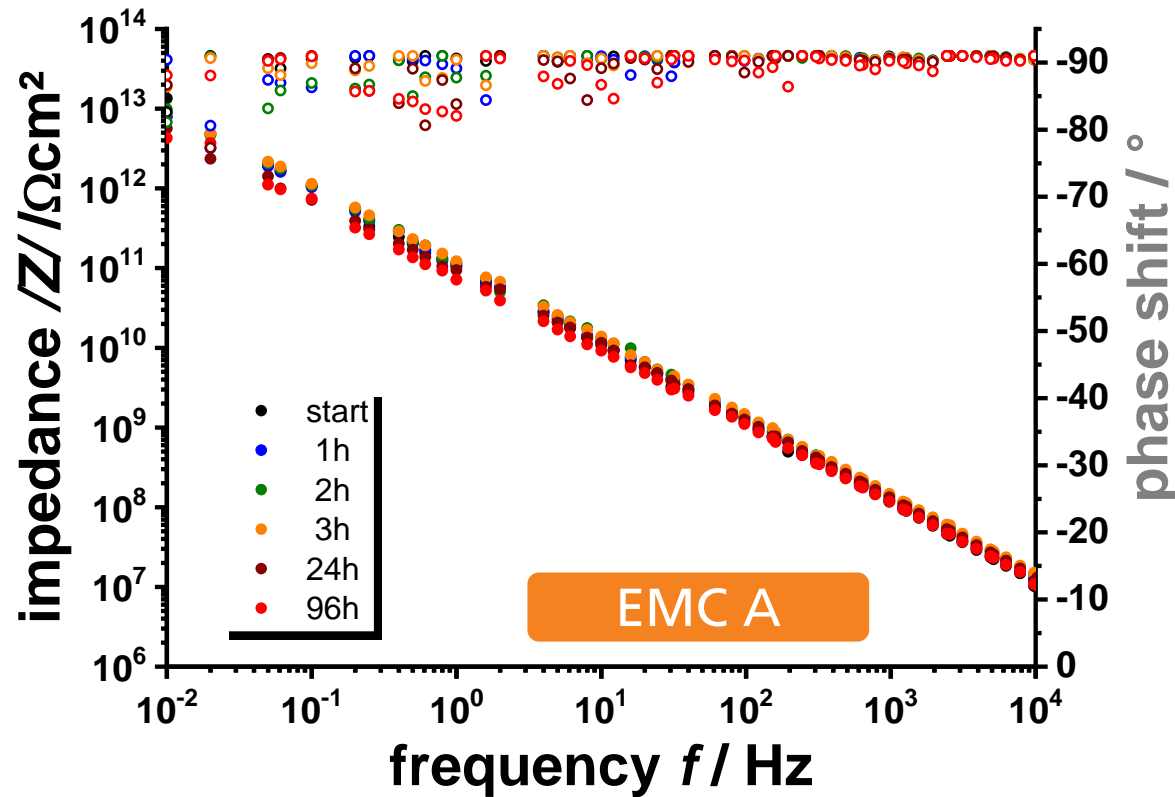
- **EMC B**
(Glass fiber reinforced)

- Resistivity: $10^{15} \Omega \text{ cm}$ (25°C)
- Permittivity: 5.4 (25°C; 50 Hz)



Solid-state impedance spectroscopy

Comparison of different mold compounds





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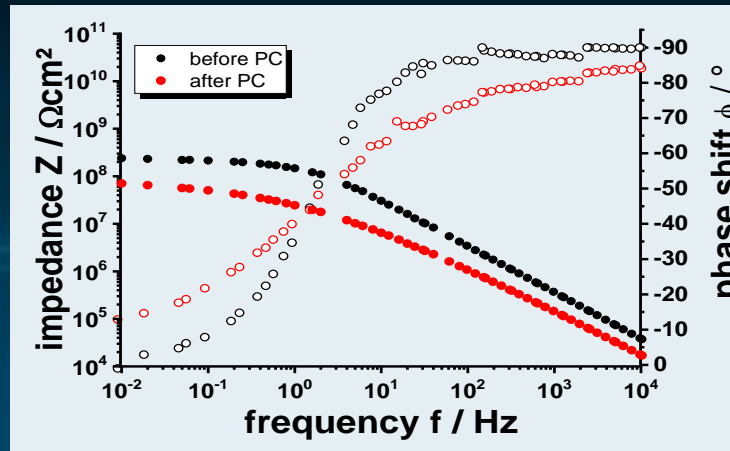
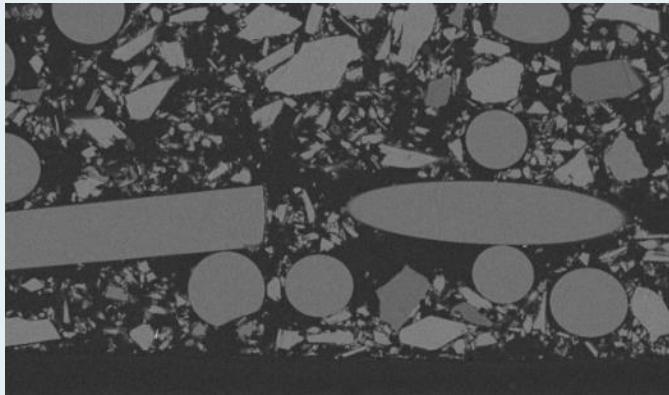
Vision & Summary

Summary

Impedance spectroscopy: » Measuring Relation between voltage and current flow in dependency of the frequency.«

Industrial application: »Application control, material & process optimization, state of health analyzes«

Material parameters: Calculation of permittivity, resistances, defect areas



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Thank you for your attention!