NEW HAST AND NON-DESTRUCTIVE EVALUATION METHODS FOR POWER MODULES

2025/10/08 – Bordeaux, France

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NEW WACK GROUP HEADQUARTERS

Growth
needs space

New HQ in Baar-Ebenhausen
(south of Ingolstadt)

- Plot Area: 60.000 m^2
- Staff capacity: 400
- Completed: May 2024

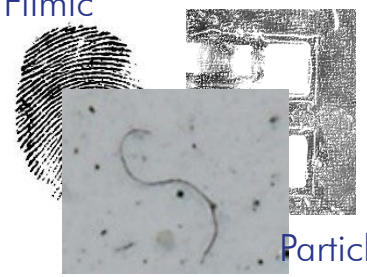
ZESTRON - AT A GLANCE

WE SUPPORT CUSTOMERS FOR ALL SURFACE & RELIABILITY RELATED QUESTIONS IN ELECTRONICS
TO PREVENT AND ELIMINATE RELIABILITY PROBLEMS

Surfaces

Reliability requirements

Contaminations



Services offered

TECHNOLOGY COACHING

ANALYTICS / TESTING

SURFACE TREATMENT

Technical Centers

Ready for sustainable business relationships

- Quality Management — ISO 9001
- Environmental Management — ISO 14001*
- Information Security — ISO 27001 / TISAX® **

* Final certification planned in 2026 / ** ISO 27001 and TISAX® currently limited to German HQ

MOTIVATION: HV-EV UNITS REQUIRE HIGHER RELIABILITY

Volvo Recalls Nearly 73,000 Plug-In Hybrids Due to Fire Risk

March 28, 2025

https://electriccarsreport.com/2025/03/volvo-recalls-nearly-73000-plug-in-hybrids-due-to-fire-risk/

Tesla Recalls Nearly 128,000 Cars in China Due to Defect

Agence France-Presse • April 11, 2022 • 2 min read

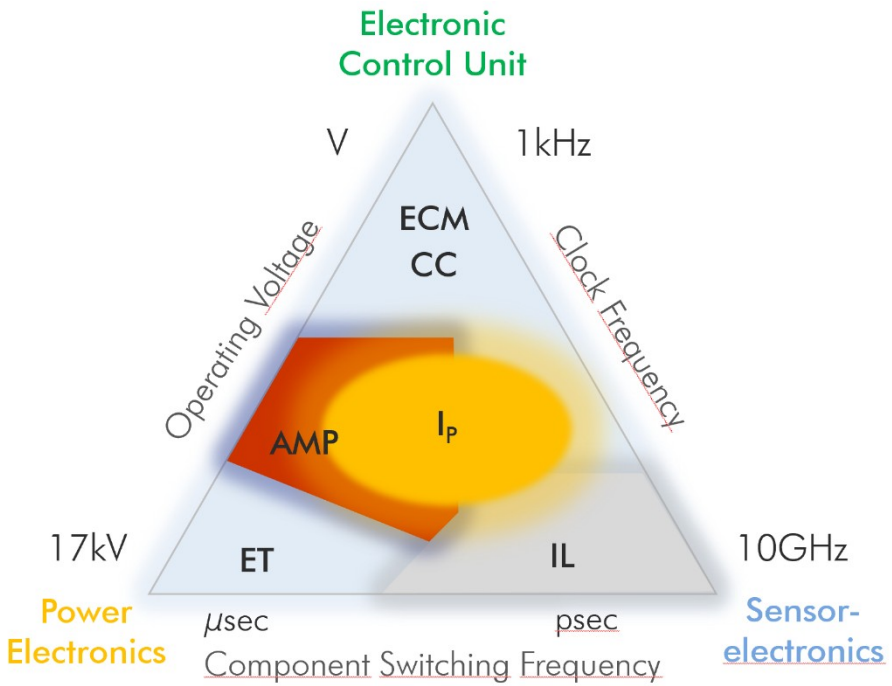
https://www.industryweek.com/operations/safety/article/21238618/tesla-recalls-nearly-128000-cars-in-china-due-to-defect

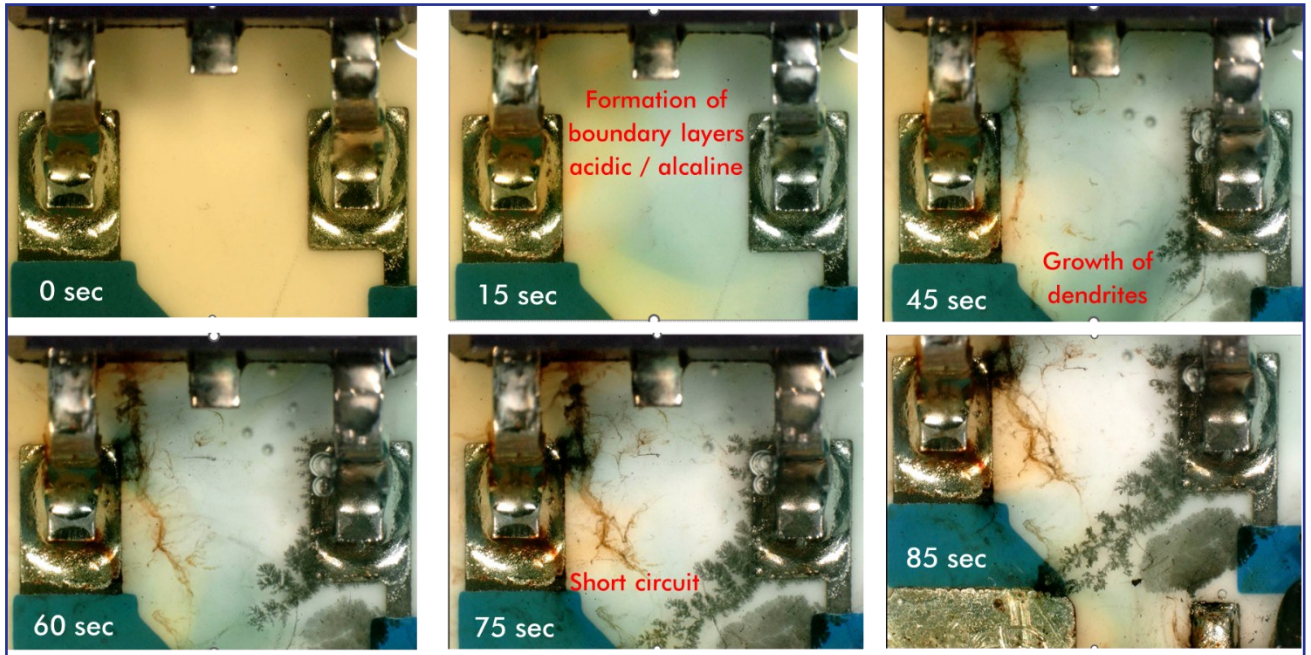
Mercedes recalls 12,308 EVs in China due to battery fire risk

Phate Zhang • Mar 28, 2025, 9:46 AM GMT+1

https://cnevpost.com/2025/03/28/mercedes-recalls-12308-evs-china/

ELECTRICAL FAILURE MECHANISMS UNDER MOISTURE





ECM lab test: short circuit by dendrite growth within 85 seconds

➡	**ECM**	**Electrochemical Migration**
	CC	Creep Corrosion
➡	**AMP**	**Anodic Migration Phenomenon**
	ET	Electrical Treeing
	IL	Insertion Loss
	Ip	Parasitic Leakage Current, Flash Overs
	PD	Partial Discharge

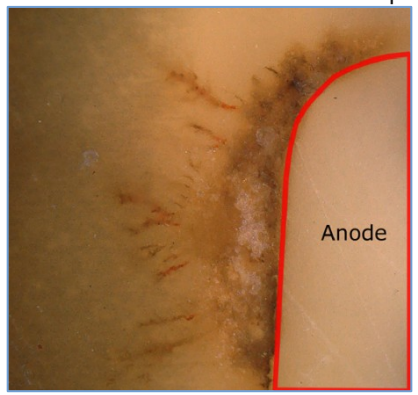
WHAT TO DO ?

- INCREASE HUMIDITY ROBUSTNESS, E.G. BY CLEANING AND SEALING THE CIRCUIT BOARDS

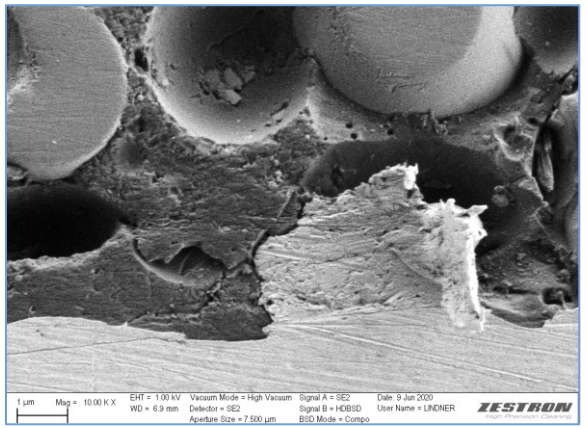
AMP: TIME-DEPENDING FAILURE MECHANISM IN ENCAPSULATIONS

AMP in embedded WBG Semiconductor

A. Brunko, M.R. Meier, M. Gloth, N. Kaminski, „Embedded systems and printed circuit boards as weak spots in HV-H3TRB tests “; ESREF; Berlin; 2022

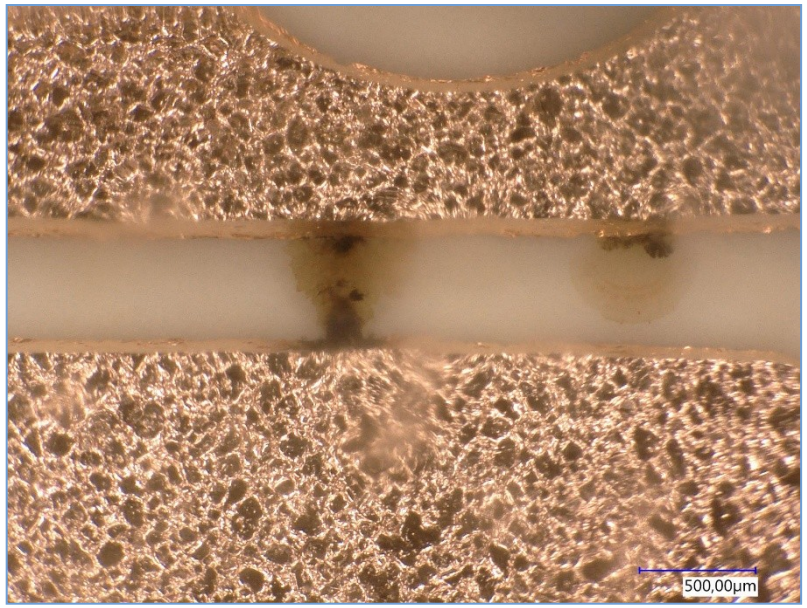


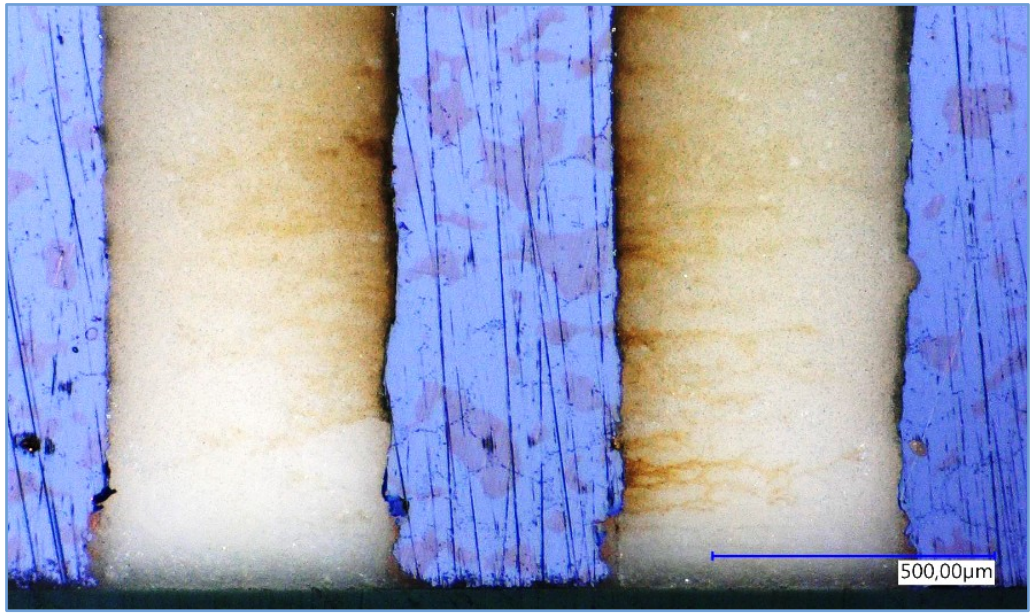
AMP in
Epoxy Mould Compound
(dendrite growth through mould)



AMP in silicone potting material in isolation trenches

(Failure from the field)

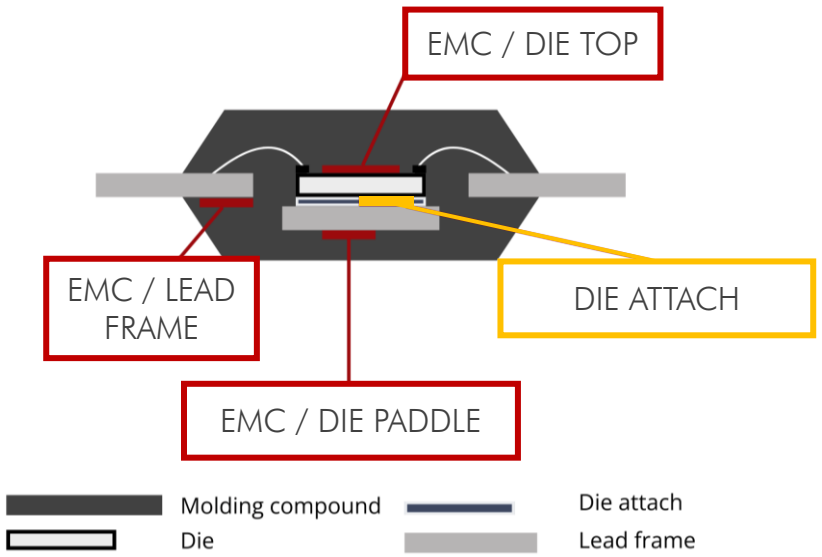




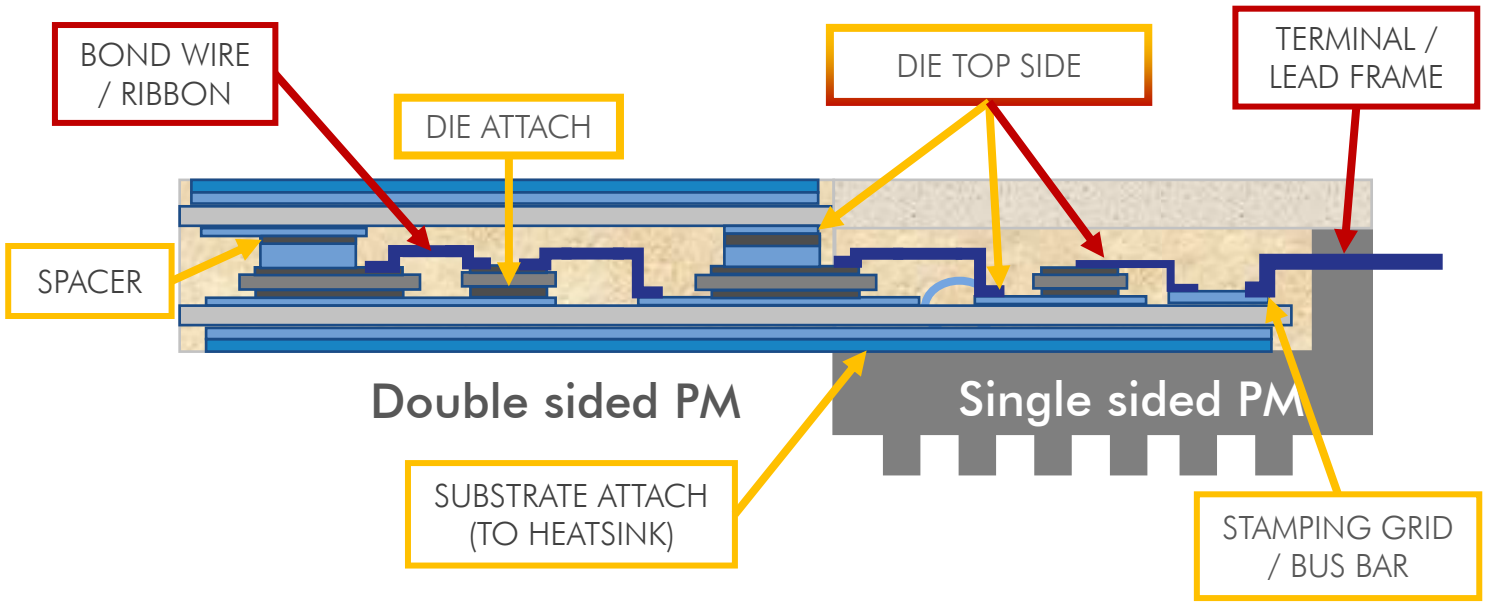
DELAMINATION AS ROOT CAUSE OF FAILURES IN POWER SEMIS

DELAMINATION RISK: BOND & SOLDER/SINTER LAYER MOLD TO METAL

DISCRETES (AEC Q101)

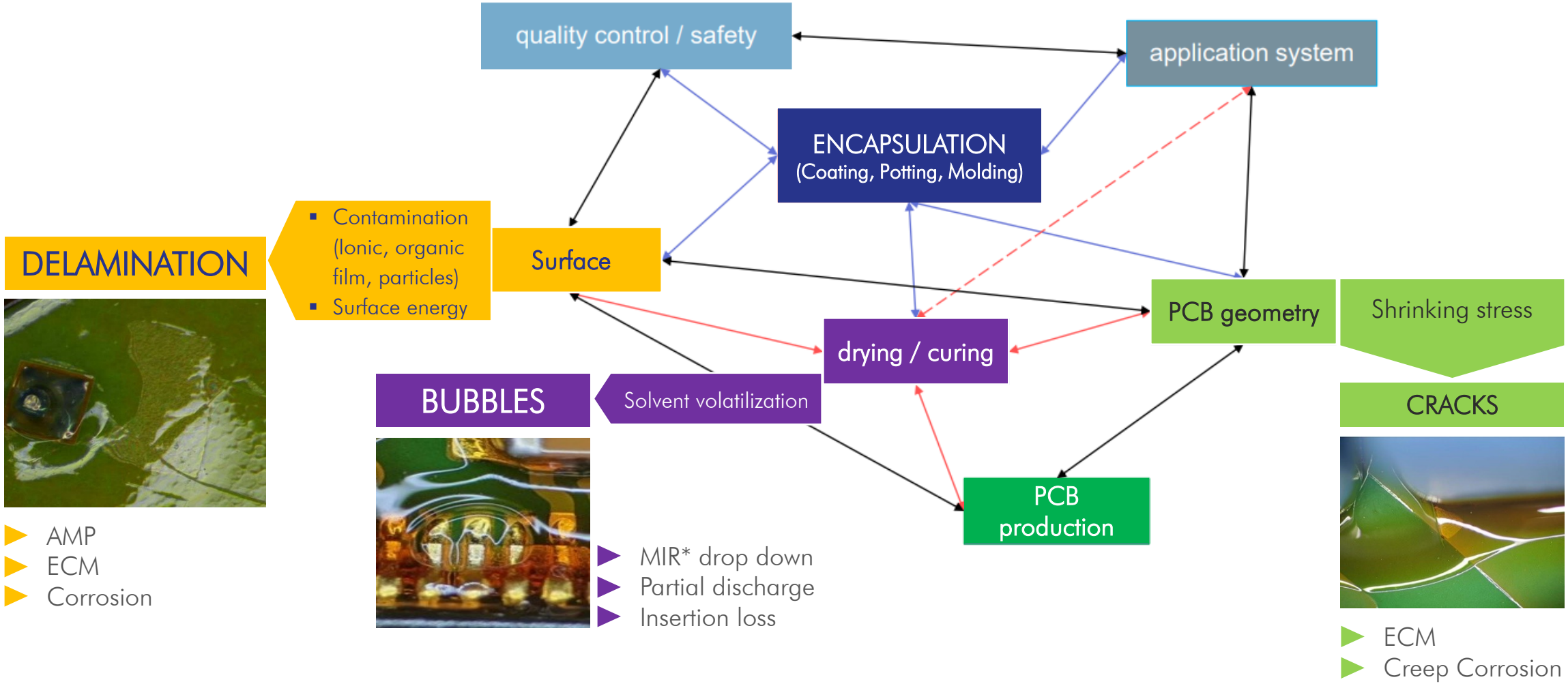


POWER MODULES (AQG-324)



➢ INCREASING AMOUNT OF TECHNOLOGIES AND MATERIALS IN USE, RESULTING IN COMPLEX DESIGN AND PROCESS CHALLENGES

ENCAPSULATION RELIABILITY – A QUESTION OF PROCESS



ENCAPSULATION RELIABILITY IS STRONGLY IMPACTED BY THE PROCESS, NOT ONLY MATERIAL AND EQUIPMENT

* Material Insulation Resistance

TYPICAL CLIMATE RELATED SEMICONDUCTOR RELIABILITY TESTS

Test Type	AEC-Q101	AQG-324	Critical Conditions
High-Temperature Reverse Bias (HTRB)	Yes	Yes	(400h)/1000h @ T_{jnom}, 0.8xV_{BR}
High-Temperature Gate Bias (HTGB)	Yes	Yes	(400h)/1000h @ T_{jnom}, 0.8xV_{Gmax}
High-Humidity High-Temp Reverse Bias (H3TRB)	Yes	Yes	≥1000h @ ~85°C, 0.8xV_{BR}, 85% RH
High-/Low-Temperature Storage (HTS/LTS)	Yes	Yes	1000h @ typical storage temperature
Thermal Shock / Temperature Cycling (TST/TC)	Yes	Yes	1000 cycles (= often 1000h)

QUALIFICATION IS SLOW AND COSTLY - BETTER PASS 1ST TIME → PRE-CHECK WITH HAST

Test Type	AEC-Q101	AQG-324	Critical Conditions
Autoclave / Biased / Unbiased HAST	Yes	-	96h, >120°C, 85-100% RH, (0.8x V_{BR})

Further Ideas: CoRe & Iodine Vapor Test

COATING RELIABILITY (CORE) TEST ACC. TO IEC PAS 61191-10

IEC standardized quality assessment method for optimizing the INSULATION process

Identifies:

- Process indicators, coating defects and adhesion problems
- Humidity robustness related to ECM and AMP

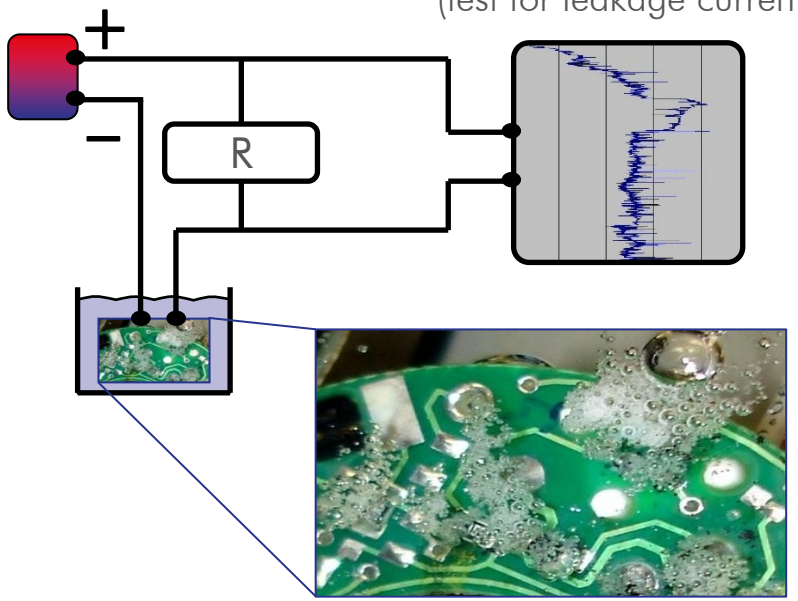
How:

- DUT is operated in de-ionised water at nominal voltage
- Water diffuses through the insulating layer (coating)
- Current consumption is measured and recorded over time

Advantage:

- Short feedback loop (1h to max. 168h [AMP])
- Sufficient condition to pass long term climatic stress test (>1000h)
- Design loop time shortened and cost reduced

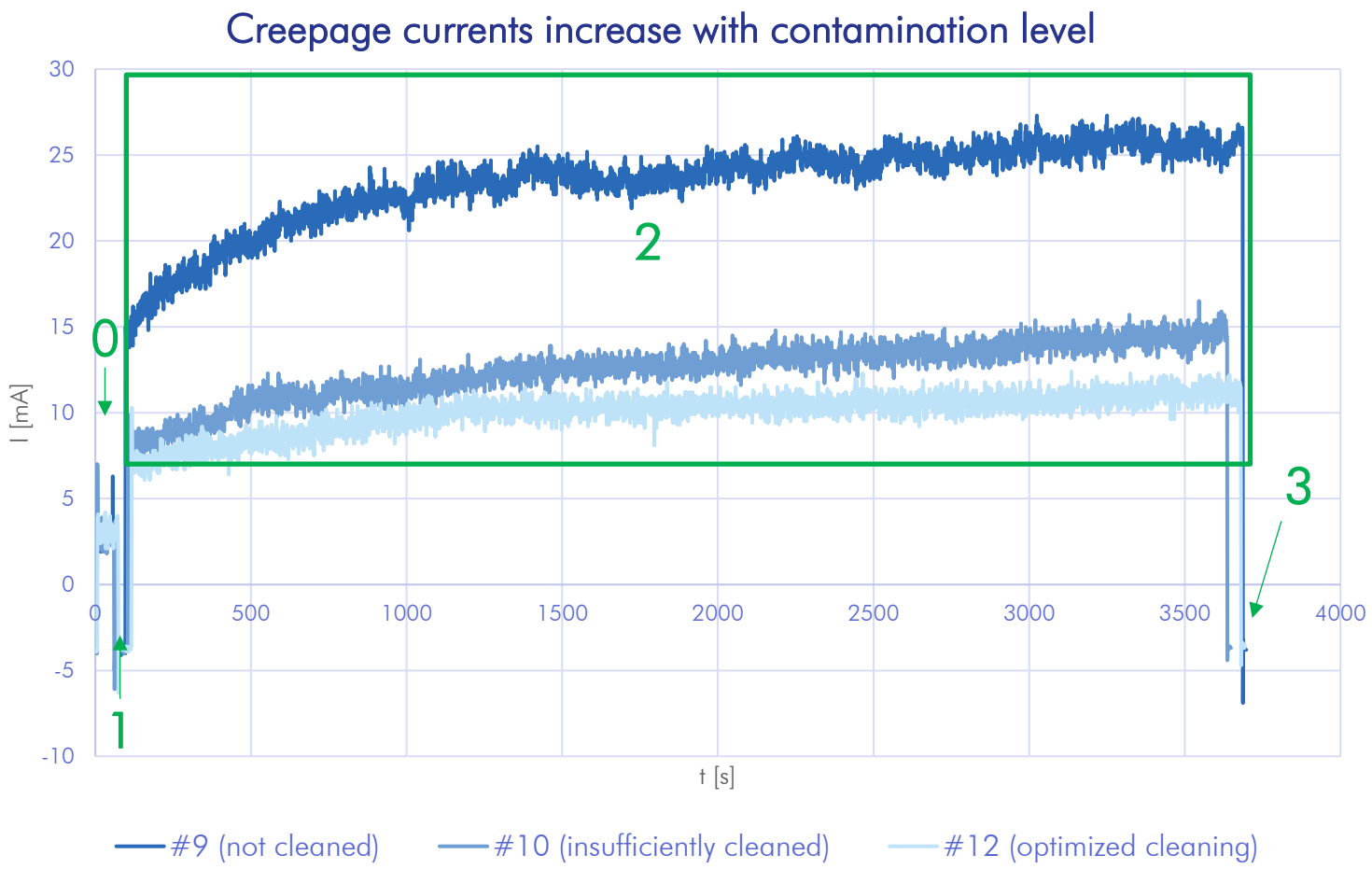
Standby current over time
(test for leakage currents)



Immediate gas
development at weak spots
(optical assessment)

EXAMPLE: HV EV PCBA - ECM

HV Coating Reliability Test acc. to IEC PAS 61191-10 (1 h max.; 800 V)



Immediate, significant gas development on the entire assembly directly after immersion in water (#9)

Formation of dendrites shortly afterwards (#9)

Test phases

0: dry running under stand-by voltage

1: switch off and place the assembly in de- ionized water

2: assembly under HV

3: HV switched off

FAST QUALITY TESTING WITH IODINE VAPOR TEST

Validation of power modules requires especially:

- Harmful gas testing, i.e. MFG or FoS

  → Failing this test → time loss and cost increase

  → Iodine Vapor Test helps to prepare for this test and secure a pass

What is Iodine Vapor Test (IVT)?

- Fast quality test method for high accelerated climatic stress testing
  - → qualitatively comparable with MFG and FoS testing
  - → Alternative HAST test
- For the qualification of power modules with transparent potting
- To be included in standards – in discussion

How does Iodine Vapor Test (IVT) work?

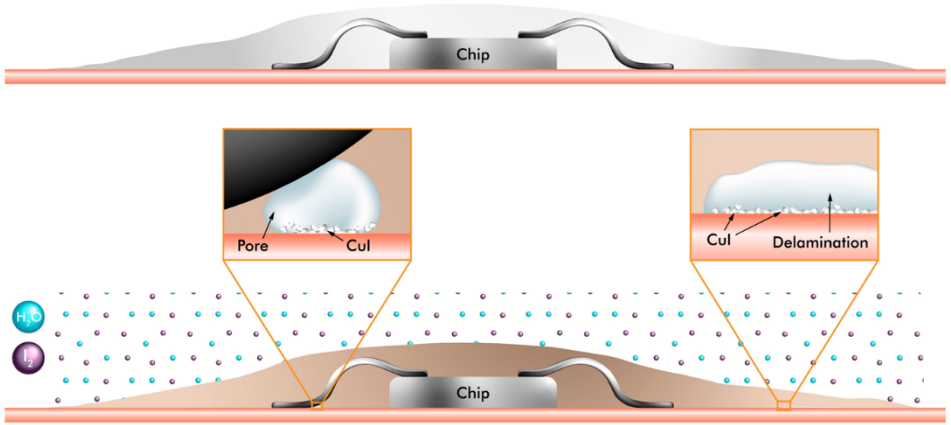
- Localizes cracks and penetration paths in the potting
- Localizes delamination and adhesion weak points between the substrate surface and the potting

Conventional harmful gas tests:

- Require the use of toxic gases (i.e. H_2S or Cl_2)
- Duration: up to 21 days (by DIN)

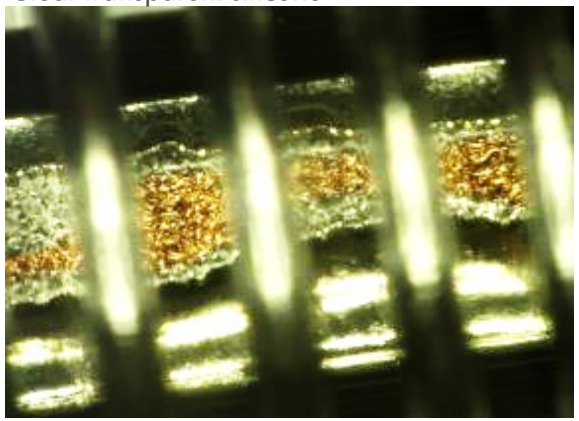
Iodine Vapor Test:

- Using ZESTRON® HAST Corrosion Indicator
- Typical test conditions: 60 °C; 1-3 h

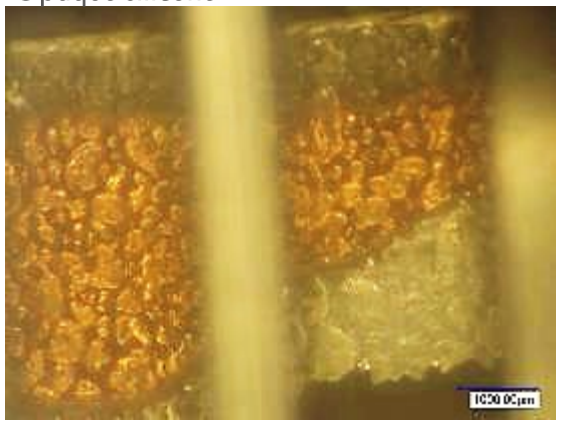


EXAMPLES – DEFECTS VISIBLE BY COPPER IODIDE

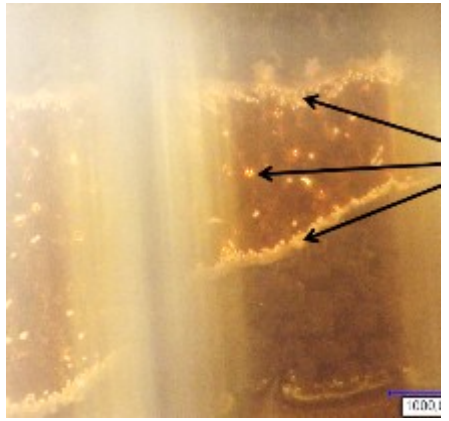
Before the test:
Clear transparent silicone



After the test:
Opaque silicone



Interference contrast makes CuI visible

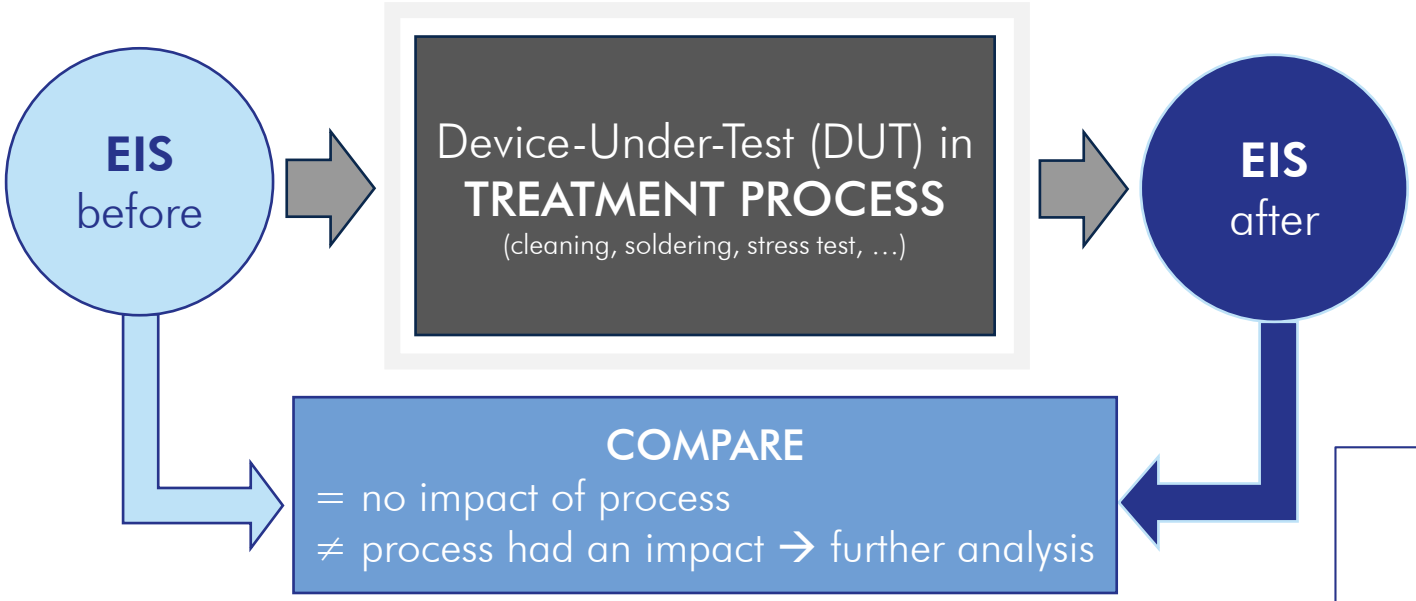


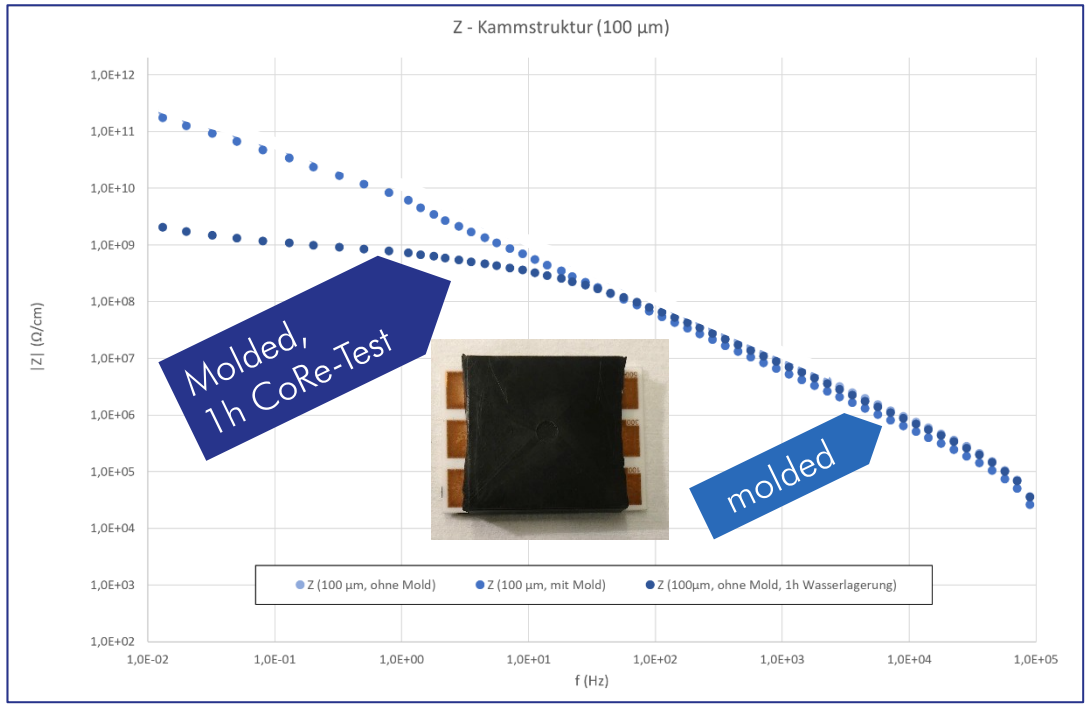
Crack & Delamination in
Parylene Coating on Cu-AMB

Local defects / Pore

Local defects / Delamination

COMPONENT CHARACTERIZATION BY EIS





Example: Transfer Mold DCB

Impedance spectroscopy of test comb DCB before and after transfer molding & after 1h CoRe-Test for humidity robustness

➢ Impact detected, humidity robustness to be further investigated

COMPONENT CHARACTERIZATION BY EIS

Electrical Impedance Spectroscopy (EIS) is an option to assess non-transparent encapsulations

- Measurement of electrical impedance of a device/component over a wide frequency range with a small signal AC voltage
  - **More sensitive than CSAM or X-Ray**
  - **Method to detect defects and process indicators in non-transparent systems, i.e. molding**

USE FOR PROCESS EVALUATION

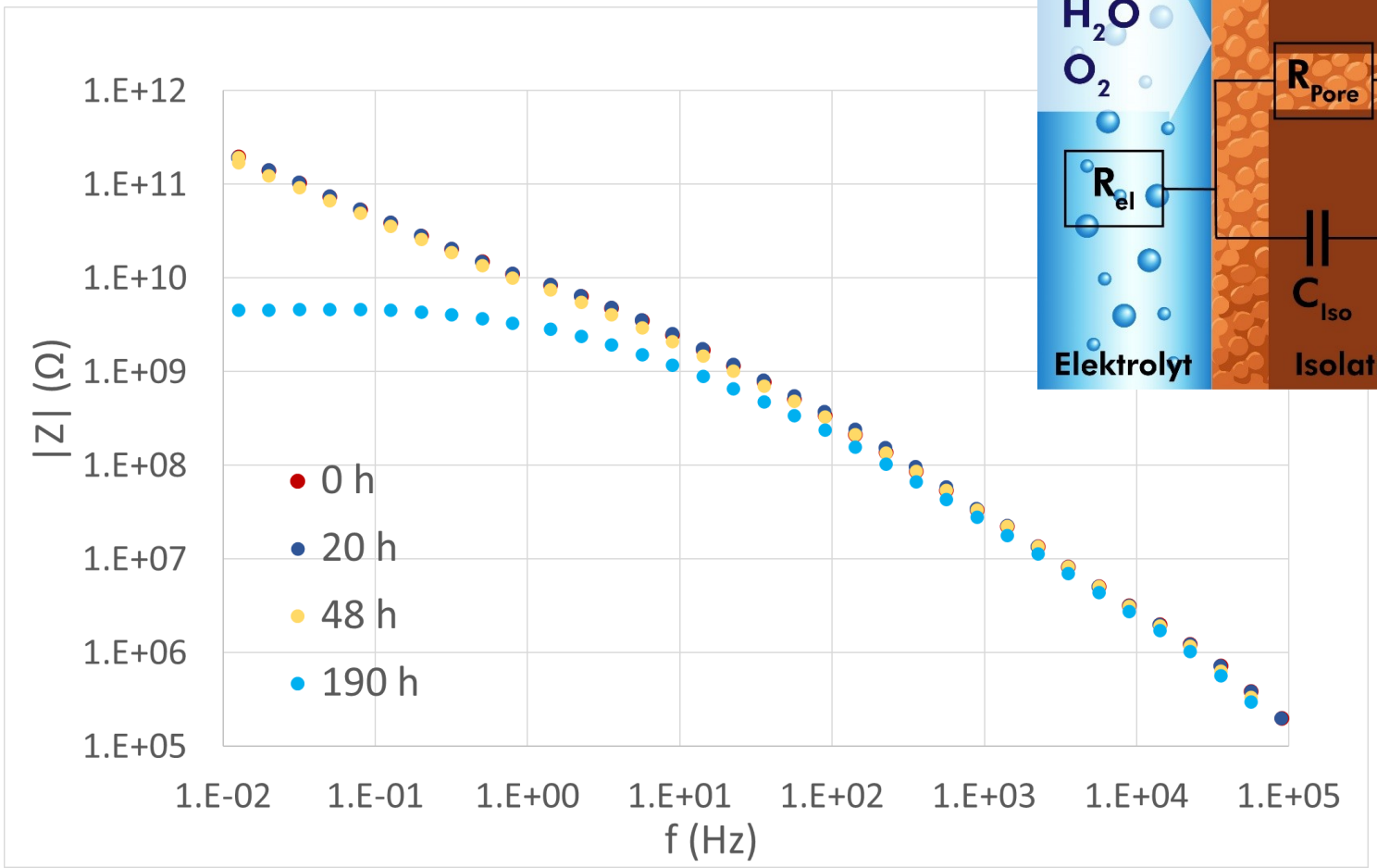
- Electrical characterization of DUT before and after stressing
- Comparison of impedance characteristics → check for differences

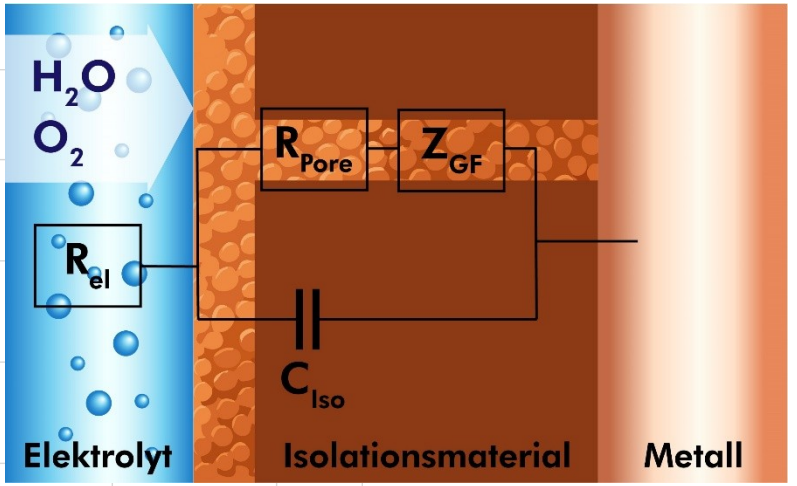
EIS characterization:
- ✓ Fast
- ✓ Non-destructrive
- ✓ No electrochemical impact

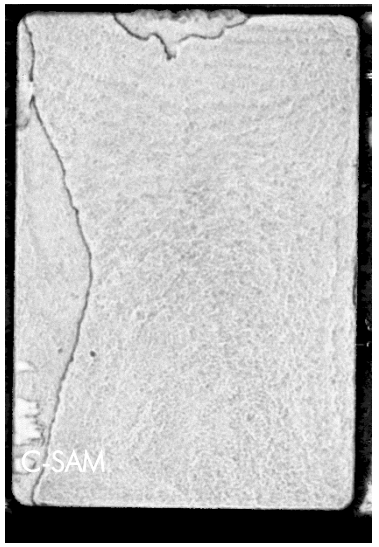
- *Standard method in IEC 61189-2-720: Detection of failures in joining structures*
- *Standard method in IEC 60068-2-88: Resistance of components and assemblies to liquid cleaning media*

BMBF PROJECT: TTM-PROCESS RELIABILITY

Isolation capability reduction by water impact:







SUMMARY

1) Humidity induced failure mechanisms are critical for the reliability and lifetime of (power) semiconductors.
   - ➢ Delamination of encapuslation materials are a major root cause for electrochemical failures.

2) Extensive climate testing is done during qualification, but failure during those tests cost time and money.
   - ➢ Preliminary HAST improve the confidence level to find design weaknesses before final qualification.
   - ➢ Multi-modal tests (like CoRe and IVT) deliver quick results and accelerate design cycles.

3) Non-destructive, but humidity sensitive analytical methods like EIS can help to detect degradation of non-transparent isolation systems, even if electrical parameters of the DUT are still within acceptable range.
   - ➢ EIS is established for coating processes (e.g. IEC 61189-2-720), but so far rarely used in semi packaging.

Let's discuss your experiences and ideas!

ZESTRON

Thank you for your attention!

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BACKUP

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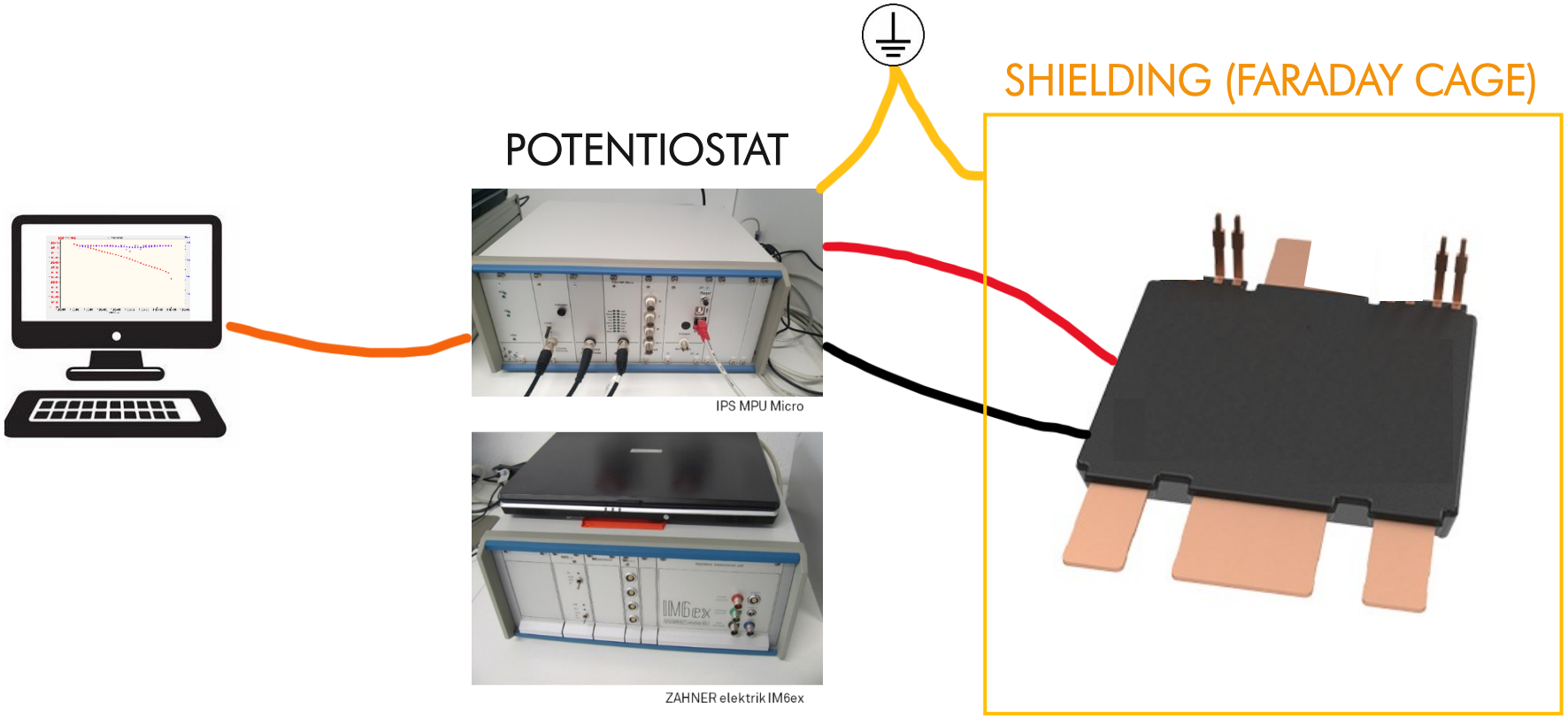
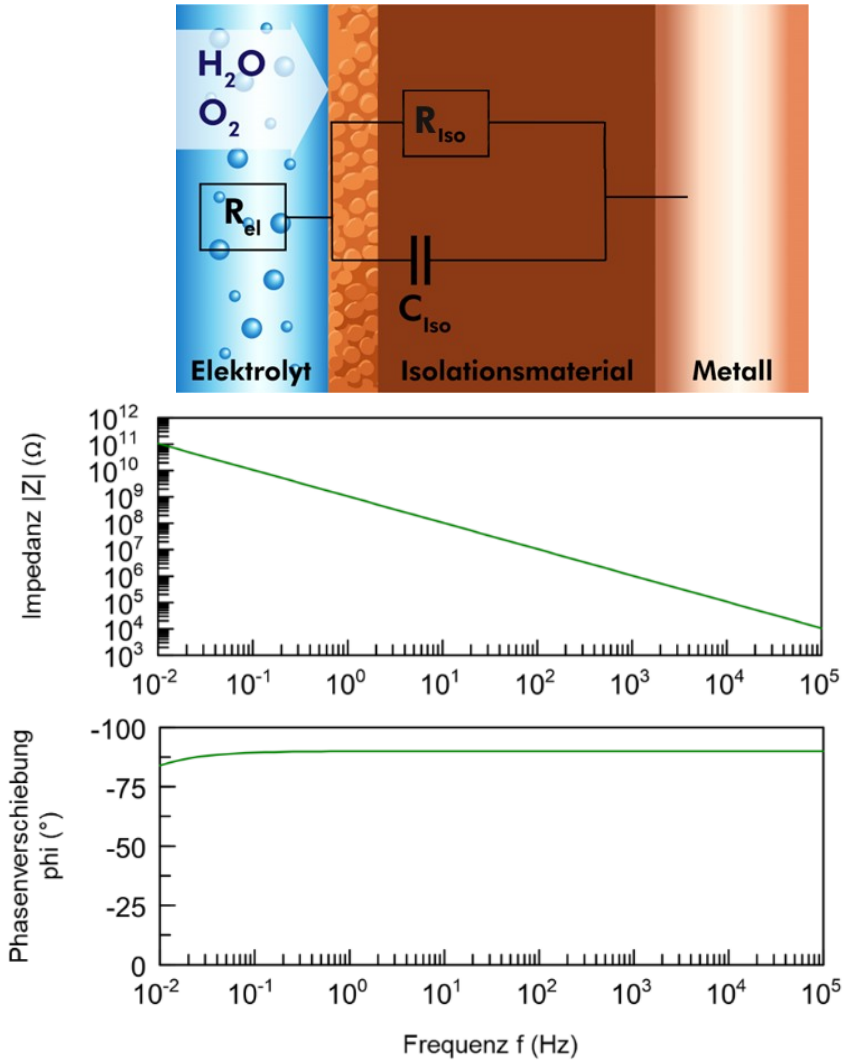
ELECTRICAL IMPEDANCE SPECTROSCOPY: MEASUREMENT SETUP



frequency range:	1 mHz – 1 MHz
Operating mode:	potentiostatic or galvanostatic
AC amplitude:	up to 3 V / 2 A
DC signal:	up to 10 V / 3 A

EIS: IMPACT OF ISOLATION DEFECTS UNDER HUMIDITY

INTACT INSULATION MATERIAL



POOR INSULATION MATERIAL