ArchitectECA2030

SC 3 Demo 3.2 Key Card

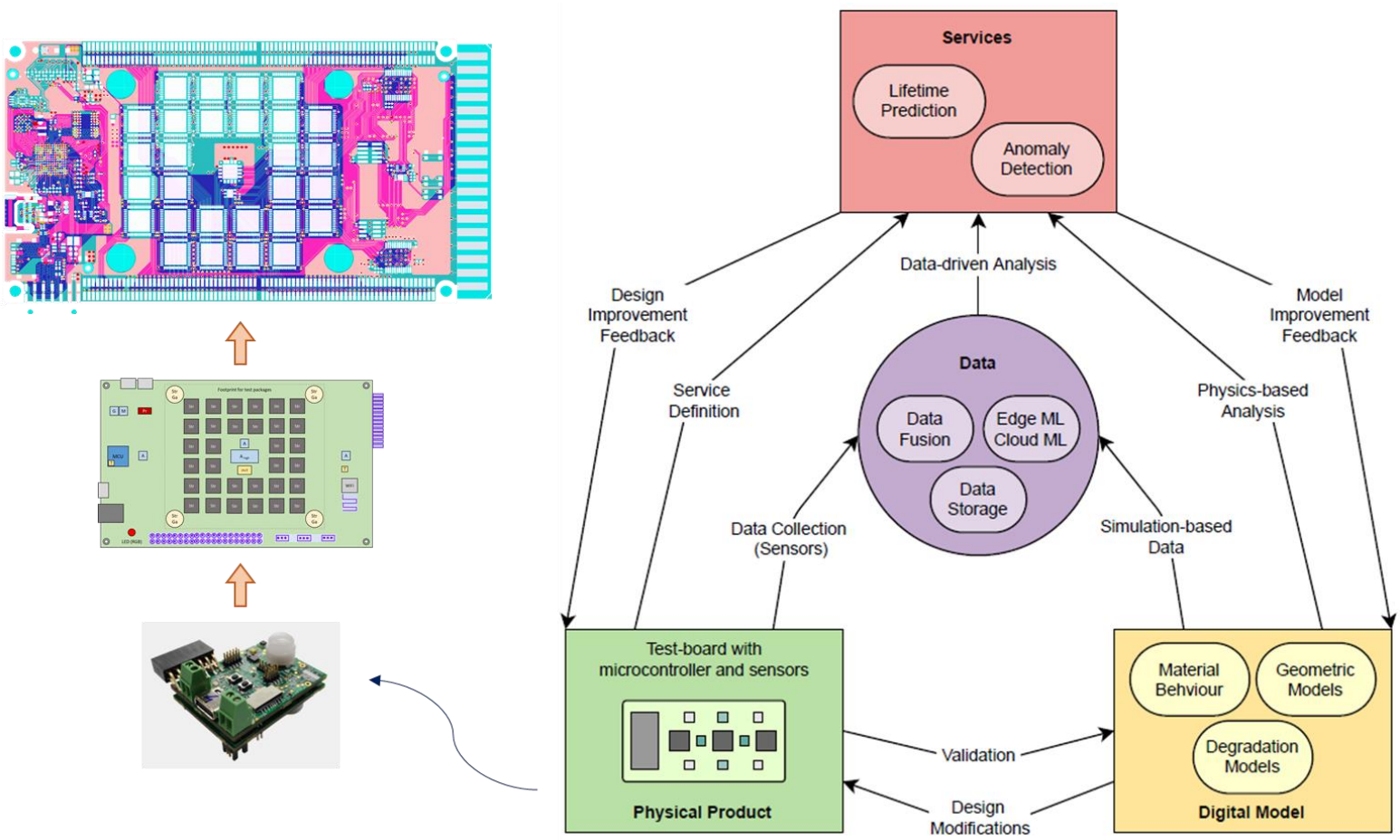
Digital Twin Package Monitoring (DigiPack)

Main aim			
• Develop physics-of-degradation and data-driven models combined with the Digital Twin technology for lifetime monitoring and design for reliability			
Partner	NXP, TUDE		
ECS value chain	Research / Tier 2		
State-of-the-art		**Beyond SotA / Innovation**	**Targeted TRL**
• Electronic packages exposed to harsh operating conditions undergo degradation of its constituent materials, which can lead to package-level and board-level failures. • Current reliability assessment methods are limiting as they follow standard qualification tests on a small sample set and do not address the need of health management of individual components. • There is a need to develop new ways of reliability prediction which include component-specific condition monitoring.		• Developing models for relevant degradation (ageing) mechanisms to be integrated into a physics-based Digital Twin virtual model of a test component. • Defining the design requirements of a test-board component for DT demonstration. • Developing methods for in-situ degradation monitoring.	TRL 4

Link to project objectives		
Objective	***Addressed (Y/N)***	***How***
O1 – Continuous robust design optimization for each part in the ECS value chain	N	N.A.
O2 – Framework for safety validation of ECS value chain	N	N.A.
O3 – Identification & management of residual risks over the entire ECS value chain	Y	Digital Twinning and physics-of-degradation models provide insights on component degradation, thus managing failure and reducing residual risks.
O4 – End-user acceptance by trustworthy ECS value chain	N	N.A.
O5 – Zero emissions, zero crashes, zero congestions by ECA2030-car	Y	In-situ degradation monitoring would enable detection of early signs of component failure, thus, avoiding associated risks or accidents.

Joint demonstrator (JDEM 4)		**Linked supply chains (Y/N)**		**Considered MonDev layers**	
DEM3.1	**DEM3.2**				
		SC1	N	**System (S)**	N
		SC2	N	***Subsystem (SS)***	N
C		**SC3**	Y	***Component (C)***	N
	SC	**SC4**	N	***Subcomponent (SC)***	Y

Setup



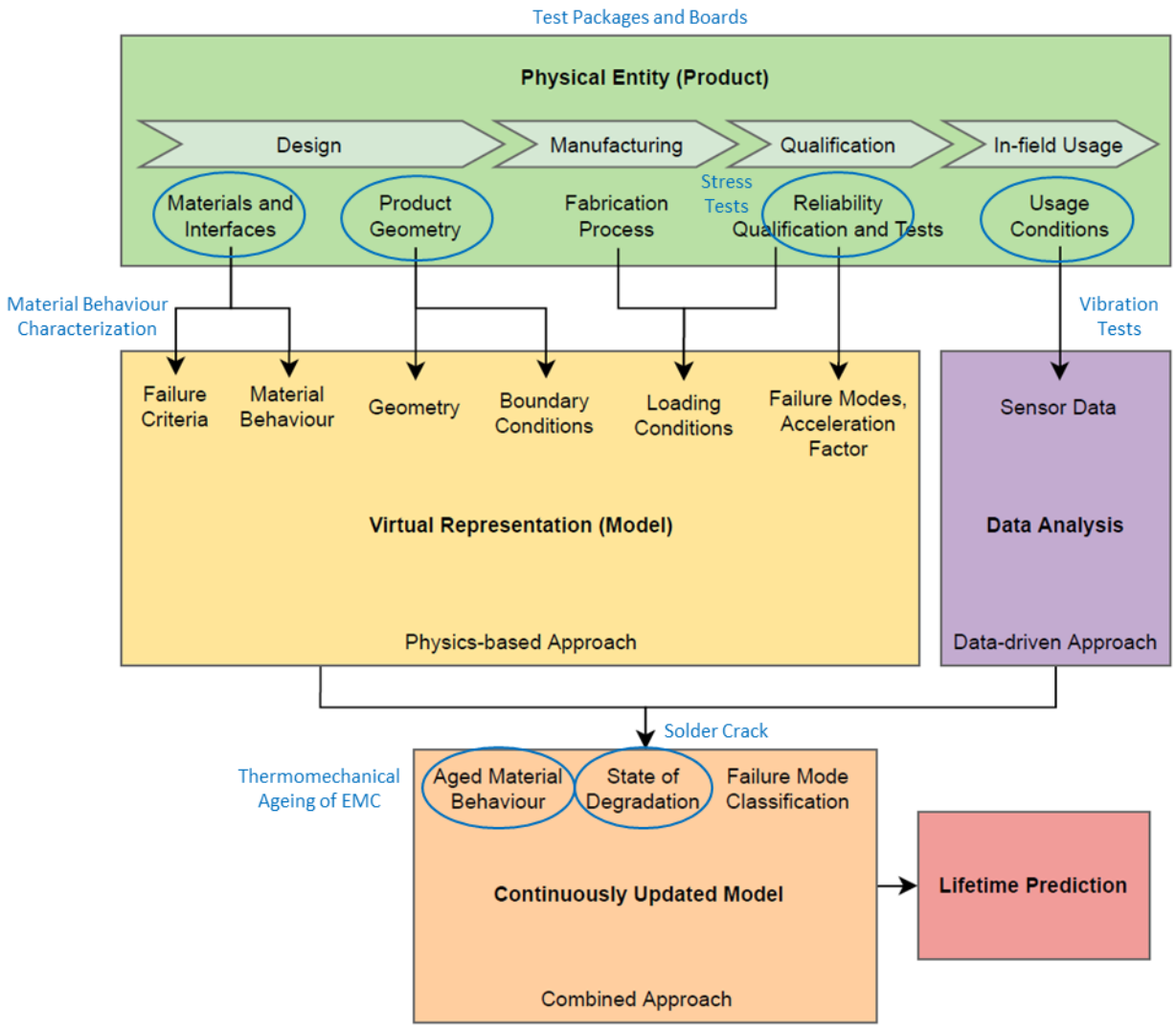
A five-dimensional Digital Twin model adopted for prognostics and health management of microelectronics compoentens is shown in the figure. A test board equipped with variety of sensors is developed as the `physical product‘, and it‘s modified version is designed and fabricated. A physics-based

degradation model is prepared for modelling package-level thermomechanical degradation. Real-life vibration profile data is collected to replicate in experimental tests for board-level degradation and failures.

Benchmark scenario/mission/etc.

Research Targets with ArchitectECA2030 (encircled in figure):

- Studying the physics-of-degradation of materials used in electronic packaging.
- Defining the workflow of Digital Twin technology applied for PHM of electronic components.
- Identifying the design requirements of a test board for an embedded DT application.
- Modelling thermomechanical behavioural change of an electronic package due to thermo-oxidative ageing of EMC encapsulation.
- Developing an in-situ solder-joint degradation-monitoring workflow using piezoresistive stress sensor and resistance measurement.



KPIs (related to requirements)	Baseline
KPIs which evaluate the success of the demonstrator • Which parameters (variables) are being measured • How accurate can the RUL be predicted • What degradation mechanism are being considered/analysed Which failure modes are being considered	Baseline for KPIs • 4 parameters (temp., humidity, vibrations, stresses) • ±30 days • 3 degradation mechanisms • 2 failure modes

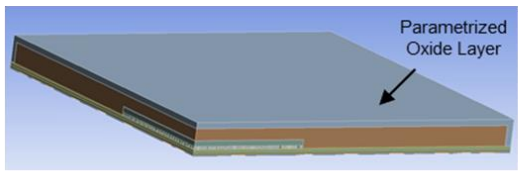
Evaluation

Evaluation platform – ANSYS for finite-element simulation, NXP CMLT and MCUXpresso

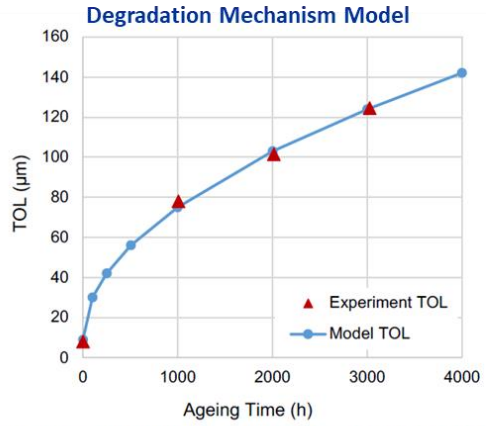
Current status/demonstration

- Package level degradation due to thermo-oxidative aging of epoxy moulding compounds (EMC) is experimentally studied and models for aging mechanism, parametric geometry, and thermomechanical behaviour are prepared. Prepared models are used to predict the package behaviour at different stages of ageing.
- Real-life vibration profiles are replicated in the laboratory to perform vibration tests on test packages to monitor solder-joint failure. Solder joint degradation monitoring was demonstrated using a piezoresistive stress sensor and four-point resistance measurement technique.

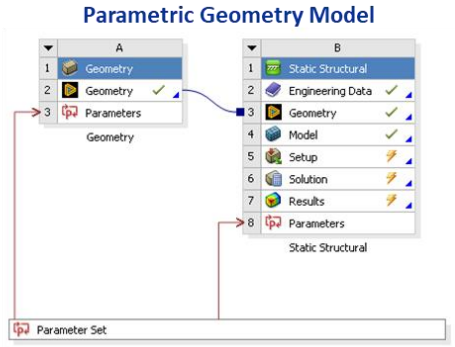
Package-level degradation – Thermo-oxidative ageing of epoxy moulding compounds (EMC)



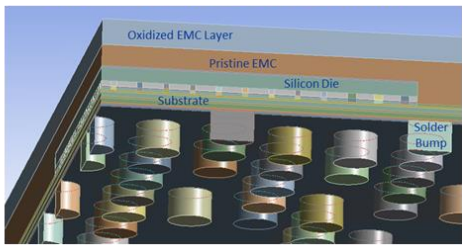
Degradation Mechanism Model



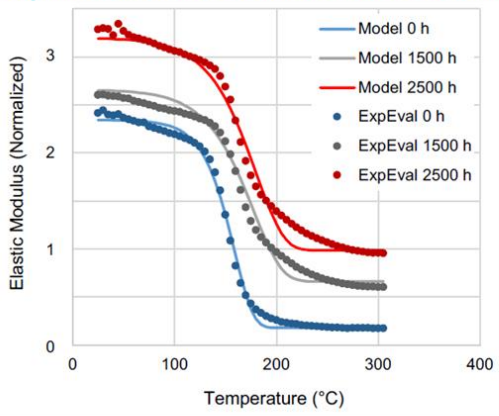
Parametric Geometry Model

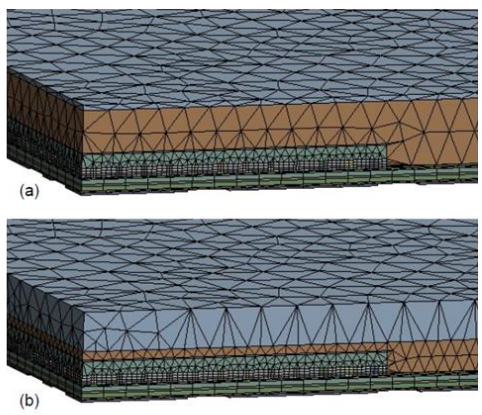


Flipchip Package Quarter Geometry



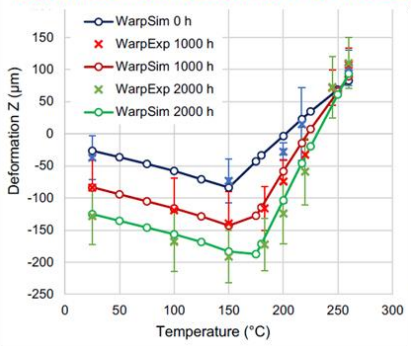
Experimental Characterization + Modelling



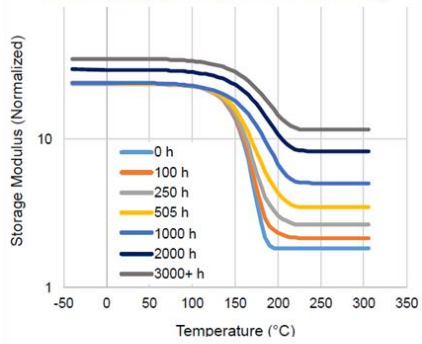


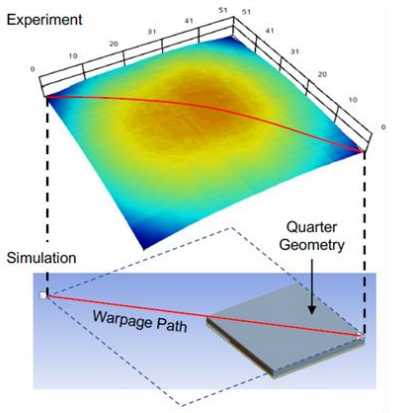
Aged Material – ThermoMechanical Behaviour

Experimental Validation of Models

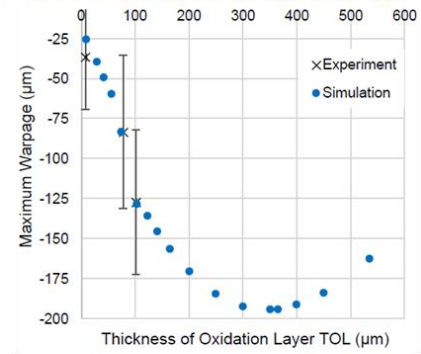


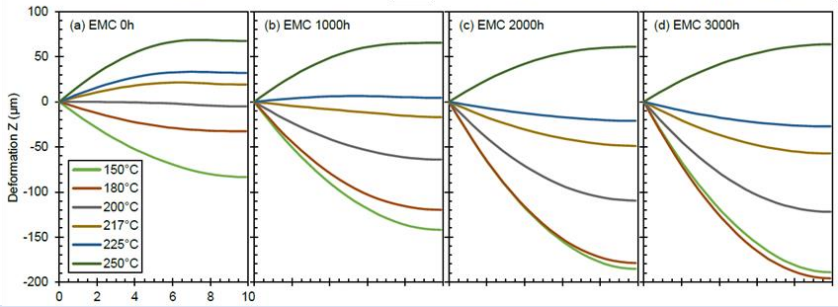
Aged Material – ThermoMechanical Behaviour (A Continuous Model)



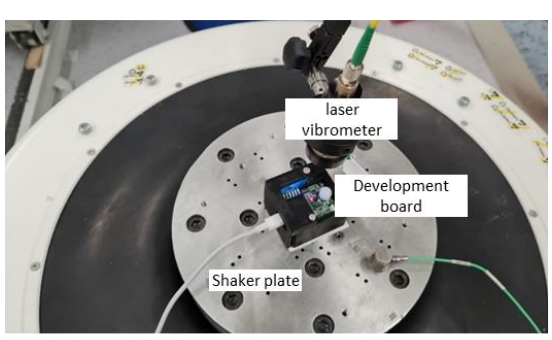


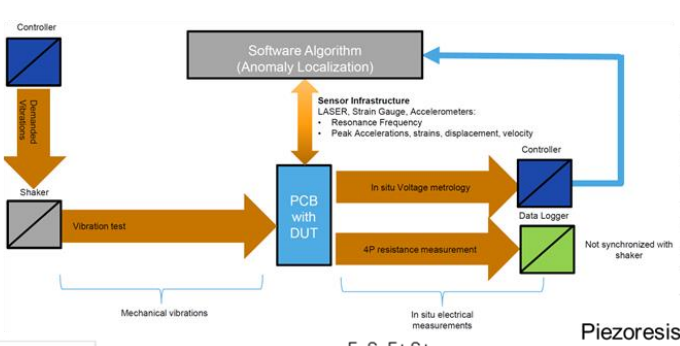
Effect of Ageing on Package Warpage

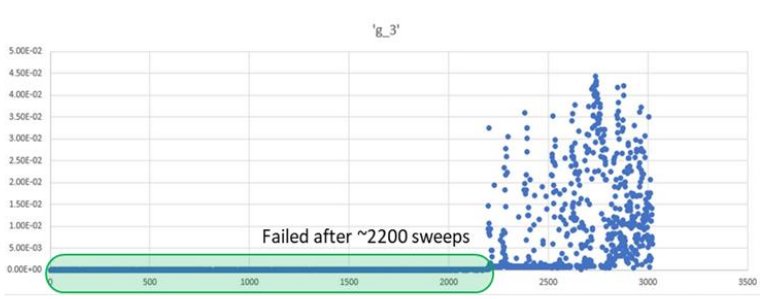


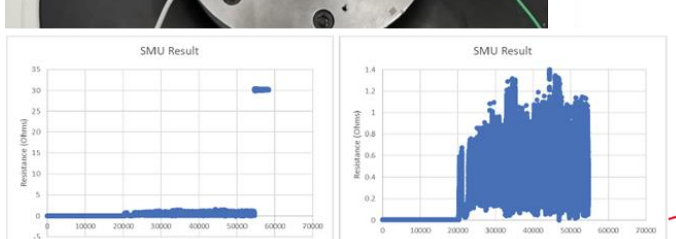


Board-level degradation – Vibration-induced solder joint failure



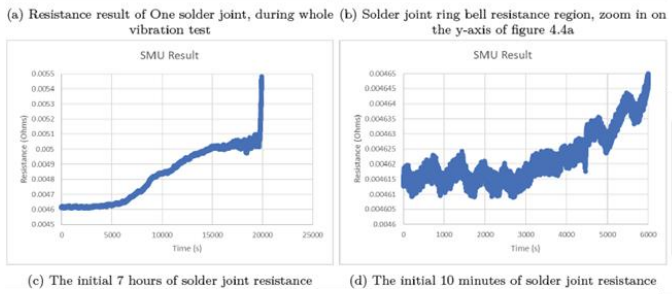






(a) Resistance result of One solder joint, during whole vibration test

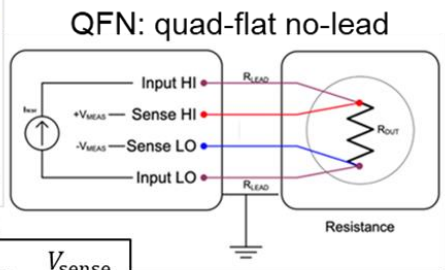
(b) Solder joint ring bell resistance region, zoom in on the y-axis of figure 4.4a



(c) The initial 7 hours of solder joint resistance

(d) The initial 10 minutes of solder joint resistance

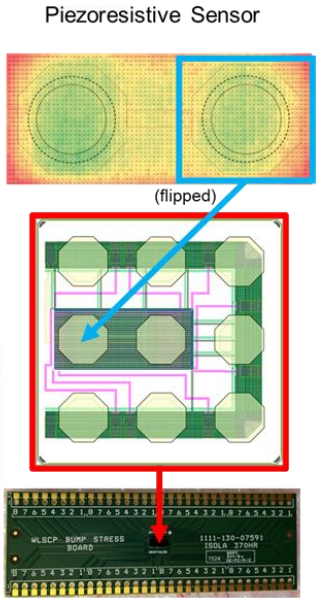
QFN: quad-flat no-lead

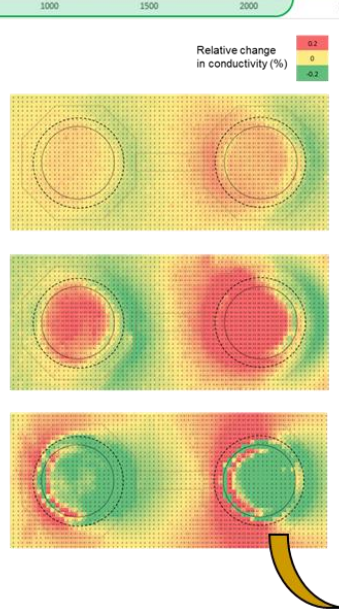


Four-point resistance measurement
(Solder-joint degradation)

$$R = \frac{V_{\text{sense}}}{I_{\text{force}}}$$

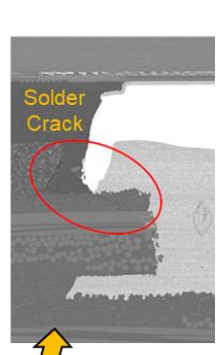
Piezoresistive Sensor





Measurement of change in conductivity of 2100 cells of piezoresistive sensor

Mechanical Bend Test



Impact

Continuous reliability assessment and failure prediction using in-situ monitoring of degradation of mission critical electronics.

Used standards

- *IPC-2551: International Standard for Digital Twins*
- *ISO 26262: Road Vehicles – Functional Safety*
- *ISO/PAS 21448: Road Vehicles – Safety of the intended functionality*
- *AEC Q100: Failure mechanism based stress test qualification for integrated circuits*
- *ISO/TR 18161: Automation systems and integration – Applications integration approach using information exchange requirements modelling and software capability profiling*

Future standardization potentials

- *Extending the standard of Digital Twin (from just the structure being described) to include related safety and residual risks.*

ECSEL JU

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