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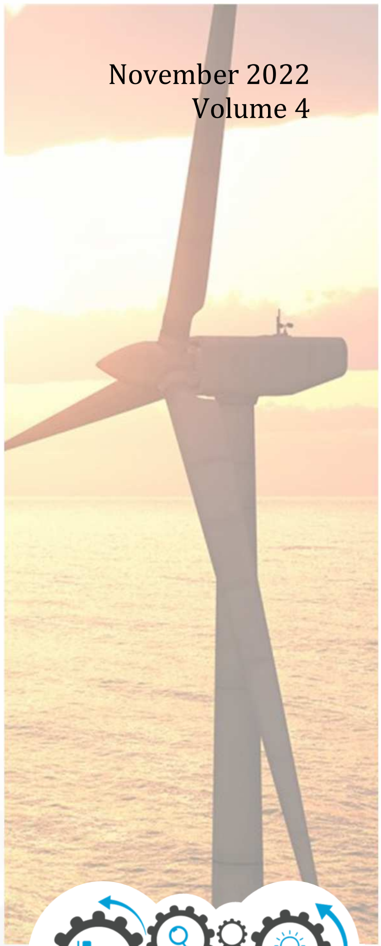


iRel40

Intelligent Reliability 4.0

Newsletter M30

"Intelligent Reliability 4.0" (iRel40) is a project with the ultimate goal of improving reliability of electronic components and systems by reducing failure rates along the entire value chain.

Welcome to the fourth newsletter of the ECSEL JU project "Intelligent Reliability 4.0 (iRel40)". The target of iRel40 is to enhance the reliability of electronic components and systems along the value chain from wafer to chip, package/ board and system throughout the whole lifecycle in the domains transport and smart mobility, energy and digital industry. iRel40 accelerates the transformation of reliability concepts, moving from stress-based, knowledge-based, and application- based approaches toward a new reliability concept based on the physics of degradation, and robustness. This M30 newsletter first introduces project objectives and key development areas, identified in iRel40. Secondly, work on eight examples of achieved technical innovations is presented. Thirdly, results were presented at five international conferences and workshops, namely EuroSimE 2022, EuWoRel 2022, ESTC 2022, IECON 2022, and ASDAM 2022. The progress of the project was discussed at the second General Assembly (GA) meeting in Ljubljana. ASDAM 2022 (co-organized by iRel40 partner StuBa), ESTC 2022 as well as the Ljubljana GA (organized by iRel40 partner JSI) meeting focused on spreading project outcomes to Eastern Europe to support strengthening the pan-European network idea.

Inside this issue

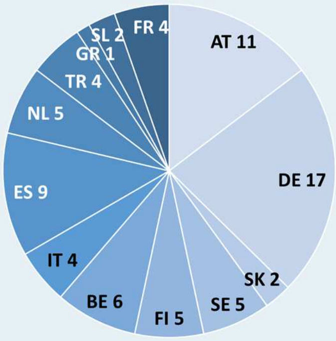
Facts & Figures

Partners: 75
Countries: 13
Budget: 101.8 Mio €
JU Funding: 24.5 Mio €
National funding 22.9 Mio €
Project Start: May 1st, 2020
Duration: 36 months
Coordinator: Infineon Technologies AG

Project organisation

The project is organized in 8 Work Packages (WP), 16 Application Use Cases (UC) and 18 Industrial Pilots (IP) which are worked out horizontally in the 6 technical WPs

iRel40 consortium
(# of partners for each country)



About iRel40 project

iRel40 comprises 75 research and industrial partners from 13 countries.

Large enterprises

Small and medium sized enterprises

R&D institutes

Project objectives and key development areas

The primary objective is to improve the reliability by reducing the failure rate. Hence, iRel40 is a nucleus for a new European reliability expert community, enabling differentiation in the electronic components and systems (ECS) industry.

- **Objective 1:** Define needs and requirements for future ECS applications to drive improvements and prediction of reliability along the value chain, chip, package, board/system – to foster Europe's competitiveness in ECS.
- **Objective 2:** Implement data value chains and cross-component data analytics to speed up the learning curves.
- **Objective 3:** Double the predicted lifetime for specific materials and load conditions for ECS applications.
- **Objective 4:** Early detection of unexpected quality relevant events along the ECS value chain by advanced and innovative control concepts.
- **Objective 5:** Reduce the failure rates and enable lifetime prediction with connected and new concepts along the ECS value chain.

Based on current and expected changes in the reliability concepts, the iRel40 project has defined five "**key research & development areas for reliability**":

- Multi-scale & multi-physics simulations for physics of degradation
- AI-based control systems in advanced production
- Smart sensoring and big data analysis
- Reliable materials and reliability testing
- Prognostic and health management digital twin for condition monitoring

In the following section, eight selected technical innovative research results related to project use cases (application use cases / UC as well as industrial pilots / IP) are presented.

#1. In-situ high temperature scanning transmission electron microscopy on VCSELs (DI-2)

Vertical cavity surface emitting LASERs (VCSELs) are widely used in sensor technologies for consumer electronics as well as automotive, medical and military applications.

In order to develop highly reliable VCSELs, an extensive knowledge of the lifetime limiting defects is of most importance. Two examples of these defects are for example climb dislocations, so-called dark line defects (DLDs) and undesired secondary oxidation processes.

During conventional failure analysis, VCSELs are typically investigated after degradation already occurred. This provides only limited information about the formation and propagation of these defects during operation.

A promising failure analysis methodology, developed by ams OSRAM AG and FELMI-ZFE, which can fill this information gap proved to be in-situ temperature scanning transmission electron microscopy (STEM).

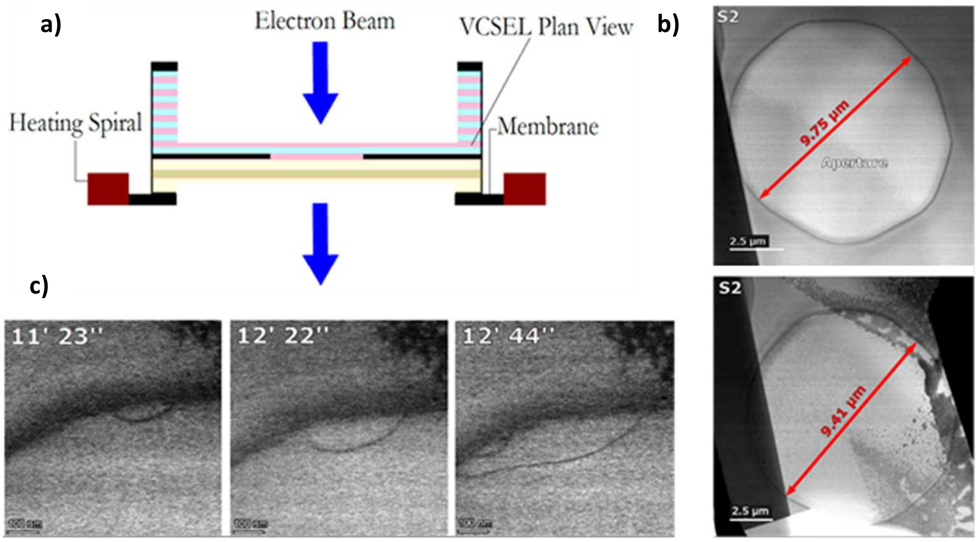


Fig. 1.1: a) Scheme of a VCSEL plan view lamella prepared on a nano-chip for in-situ heating. b) VCSEL oxide aperture in plan view before (top) and after heating (bottom). c) Time evolution of DLDs propagating along oxide aperture edge at elevated temperature.

For in-situ STEM, a VCSEL cross section or plan view lamella is prepared onto a special nano-chip designed for the Dens Solution Wildfire holder, which is compatible with the FEI Titan3™ 60–300 Austrian Scanning Transmission Electron Microscope (ASTEM) located at FELMI-ZFE. A scheme of a plan view lamella prepared on a nano-chip is shown in Fig. 1.1a.

In the ASTEM, the samples are heated up to a target temperature and simultaneously investigated.

First experiments showed that with in-situ STEM it is possible to directly observe secondary oxidation processes as well as the formation and propagation of DLDs.

For example, Fig. 1.1b shows annular dark field images of a plan view lamella before (top) and after heating (bottom). A clear reduction of the aperture diameter due to secondary oxidation is visible. It was also possible to estimate the oxidation speed at different temperatures during the direct observation of the oxidation front.

Furthermore, the time evolution of DLDs forming and propagating along the oxide aperture is displayed in Fig. 1.1c. The observations showed that DLDs formed at the oxide aperture edge after secondary oxidation and travelled along the aperture edges.

The experiments demonstrate that in-situ STEM is a promising technique to be utilized in future VCSEL failure analysis and may ultimately contribute to the understanding of VCSEL defects and help the development of future products. Further reading: https://doi.org/10.1016/j.micron.2022.103264

SELECTED TECHNICAL INNOVATIONS

#2. Assets' reliability management methodology (T-7)

IKERLAN, CAF and BATZ are collaborating in a use case with the aim of developing a holistic reliability management methodology to ensure optimal performance of critical assets over their lifetime in different operational contexts. This allows to achieve the expected levels of availability and consequently to optimize the total cost of ownership.

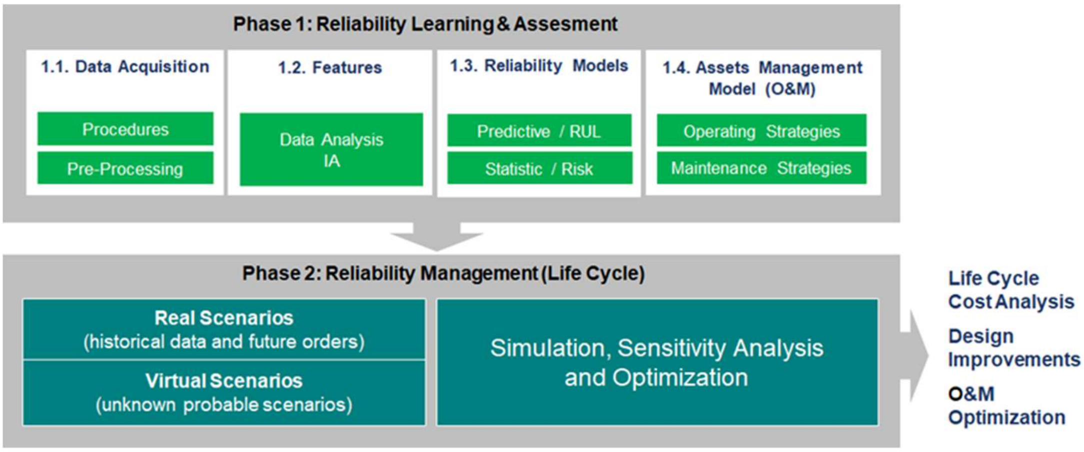


Fig. 2.1: Reliability management methodology.

The methodology helps value chain actors to study systems and components behaviour in real operating context through the Reliability Learning & Assessment phase. From the acquired knowledge, the Reliability Management phase enables them to improve decision for optimizing the performance of an equipment /asset along its lifetime, from the early design stage (where redesigns can be released), through the use stage (defining the optimal maintenance strategies), and onward.

Two types of reliability models have been developed to assess systems/ components health condition:

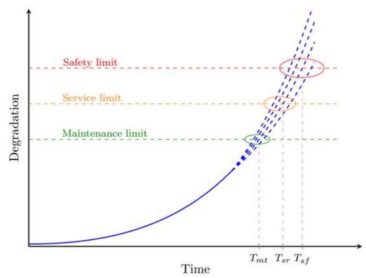


Fig. 2.2: Predictive model.

A predictive model, used for critical failures that can cause serious consequences. It is based on physical degradation, data driven or a combination of both, and allows to continuously assess the health of the components and as a result to estimate their Remaining Useful Life (RUL).

A more generalist risk model, based on statistical techniques and regression methods, which allows to estimate the risk of failure of components considering its initial design reliability and the impact of the parameters of the operational context.

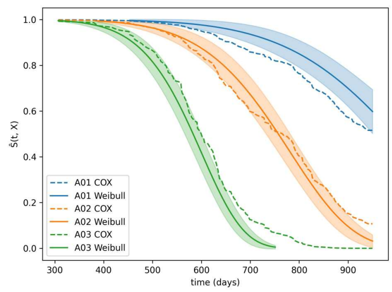


Fig. 2.3: Cox's hazard model.

The methodology is being piloted through an agent-based simulation model which studies the impact of the reliability models on tram services under different operating contexts to optimize the balance between availability and lifecycle cost (LCC) over a 4-year period. The results shows that optimisation through virtual models, using simulation and optimisation techniques, is a very useful tool in the LCC calculation and critical resource sizing of a service or for the improvement of its performance.


Fig. 2.4: Virtual simulation model.

SELECTED TECHNICAL INNOVATIONS

#3. Strategies to stepwise implement auto-pilot driven production in power module production (IP-5)

Today, the production volume of power modules is rising rapidly. To ensure reliability, quality, yield, and output over a long period of time, a high stability level for each production process is mandatory. The target vision is autopilot production, that runs perfectly stable, with equipment capable of automatically adjusting the process on a data-driven basis as enabler for intelligent reliability. Semiconductor power modules consist of more than ten different parts and materials (e.g. Si devices, substrates, isolation material, housing, solder alloy) that are assembled with a variety of unit processes. To ensure an overall stability in the production and to reach autopilot production, a deep knowledge of all critical process and material parameters as well as their interactions and their effect on reliability is needed, all integrated into an advanced control concept. Since the sustainable stabilization of a complex semiconductor assembly line is based on various aspects, a staircase approach has been developed. Starting from a profound understanding and evaluation of the critical parameters during the development of the unit process (Step 1: characterization). Thereby, all influencing material, process, and equipment input parameters as well as the output parameters are listed and classified in categories like ‘variable input parameter’, ‘constant input parameter’ and ‘critical output parameter’. In this design of manufacturability approach (DoM), the variable parameters are analyzed wrt. their impact on the output parameters especially on reliability to fix the initial process window. In step 2, the control concepts for input and output parameters are identified and their capability are proven. Closing step 1 and step 2, a stable process base for production is available. A further stabilization phase is foreseen in this concept (step 3). During ramp-up of production, by scaling up the equipment landscape, a variation in process stability from equipment to equipment is expected due to equipment specific parameters, that have not been varied during initial development. Statistical methods are typically set to fix stability targets for the output parameters as well as yield and UPH. In Fig. 3.1 the yield statistics of an ultrasonic (US) terminal welding process for several equipment is shown. Differences in the pattern recognition could be identified as root cause for the increased yield loss. In general, if the process variation can be linked to any critical material, equipment or process parameter, a complete recharacterization according to step 1 and 2 might be indicated. After the production equipment park has been stabilized, in step 4, automatically triggered alarms on all critical input and output parameters are used to early detect any shift in process output key performance indicators (KPI) and to prevent negative impact on product reliability and quality. This real time reaction minimizes the amount potential risky parts and thereby is one main key to decrease field failure rate. In step 5, automated decisions are implemented in the equipment to fully operate all production processes in the target operating window. A schematic summary of the multi-step approach to stabilize the power module production and to run autopilot mode is depicted in Fig. 3.2.

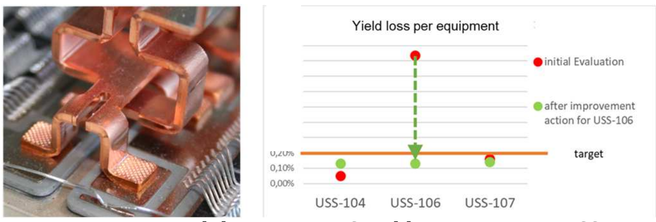


Fig. 3.1: Process stabilization on US welding equipment USS-106 by harmonization of equipment stands wrt. pattern recognition in step 3.

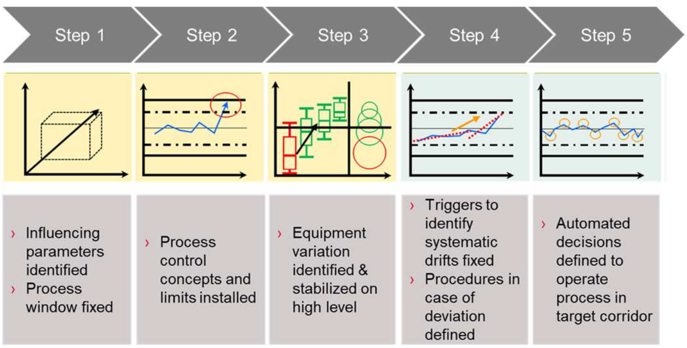


Fig. 3.2: Conceptual approach to push semiconductor backend production into automode process stabilization routine.

#4. Development of an artificial intelligence-based framework for burn-in reduction in the semiconductor manufacturing industry (IP-6)

In semiconductor manufacturing industry, burn-in (BI) is performed to screen out latent defects, which can be expected to fail during early-life stages. This guarantees the early life reliability of the electronic devices in the field. However, burn-in is expensive and time-consuming, since it requires extensive testing under accelerated stress conditions, such as high temperature. The cost is particularly relevant for new technologies, which require that the entire lots of produced devices undergo burn-in so that the very strict quality targets are met.

In IP-6, we develop a framework (see Fig. 4.1 below) to estimate the quality of a production lot by exploiting the large amount of data collected during production. Specifically, we consider three different sources of data: i) production signals measured from the machines used in the different stages of production; ii) results of electrical tests performed prior to burn-in; and iii) wafer maps data generated during the production process. With respect to production signals, they are used as input of anomaly detection models, based on stacked Long Short Term Memory (LSTM) autoencoders, for detecting anomalies of the most critical production machines. Results of electrical tests are fed to a Probabilistic Support Vector Regression (PSVR) for the estimation of the early life failure probability of the devices of the production lot. An approach based on Convolutional Neural Networks (CNN) is developed to identify health states of wafers. The outcomes of the different models are, then, aggregated to estimate the early life quality $\hat{p}$ of the production lot. p is compared with the quality target for early failures, p_{target}, and the decision is taken on no BI, conditional BI, or full BI.

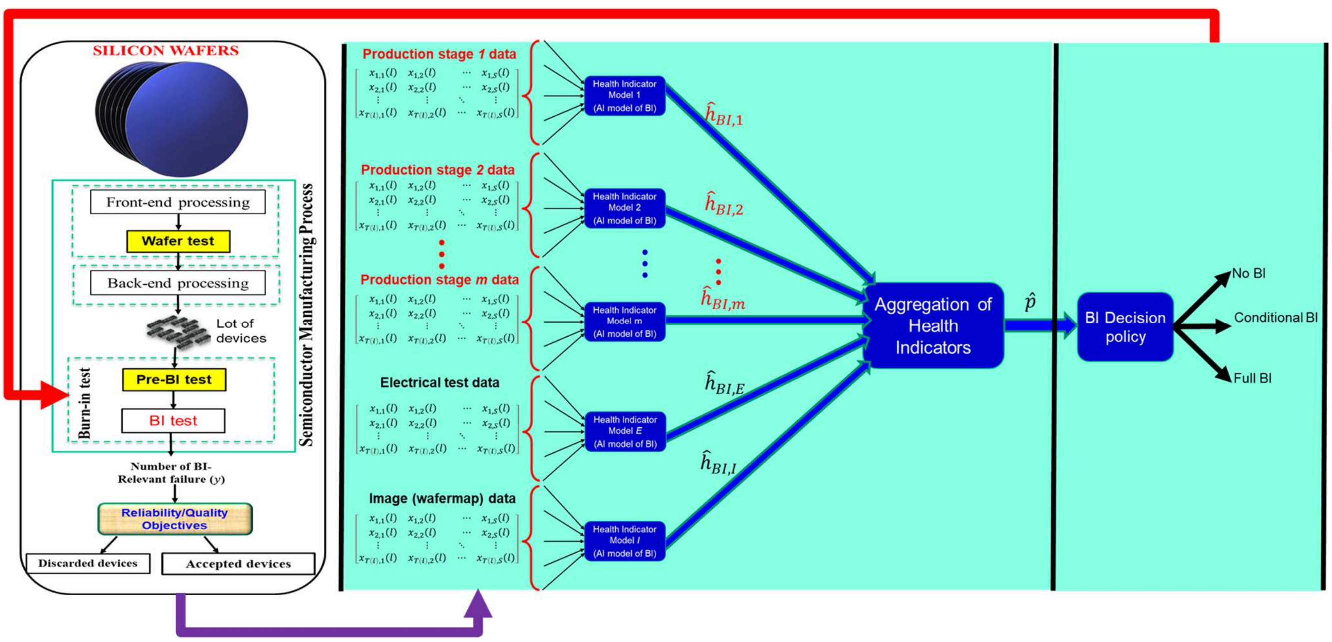


Fig. 4.1: Artificial intelligence-based framework for burn-in reduction.

#5. Conditional burn-in (IP-6)

In Industrial Pilot IP-6, a novel approach for the reduction of burn-in (BI) time is proposed. Production data available from different sources are used to estimate a health indicator *h* for individual lots. This health information is the starting point for lot-specific BI time reductions, while still guaranteeing the defined quality target for early failures, $\pi_{target} \in [0,1]$.

The health indicator *h* is a latent variable. Up to now, various AI models have been applied to estimate *h*. A LSTM autoencoder was trained on production control data retrieved from a single wafer process step. An unsupvervised learning in combination with a distance measure was used to provide health information about lots. Additionally, an autoencoder was trained on logistic production data. Moreover, a probabilistic support vector regression was performed on electrical data to infer health information.

In order to relate the health indicator *h* with the early life failure probability *p*, a logistic regression model is proposed:

$$logit\,(p(h)) = \beta_o + \beta_1 h$$

Thus, dependent on the actual value of *h*, lot-specific failure probabilities p_i are obtained. The early life failure probability *p* itself is estimated based on a so-called BI study. This is a random sample that is put to BI. Considering that the failure probability is lot-specific, the sampling process is described by the Poisson-Binomial distribution. We construct a Clopper-Pearson like interval estimator for the parameters of the Poisson-Binomial distribution to account for the sampling error.

In the next steps, we will verify the overall concept for lot-specific BI times based on simulations. Furthermore, we also work on a concept to combine health indicators returned by different AI models. Finally, the AI models are refined on production data.

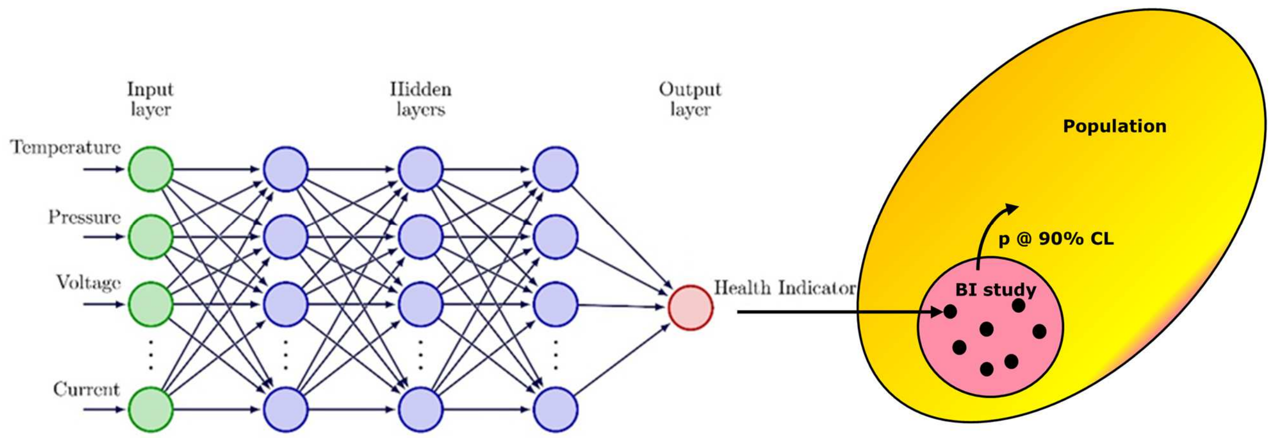


Fig. 5.1: Illustration of an AI model used to infer the health index h of lots.

#6. Imaging analysis for investigating copper – copper interfaces of vias (IP-11)

Copper micro-vias in printed circuit boards are one of the most common interconnects in printed circuit boards (PCB), since they are also considered the most robust ones. However, during the fabrication and afterwards during assembly, the copper interconnects and the base material might be exposed to higher temperatures. This increases the strain and places them at a higher risk of failure. To reveal such failure, the interconnects are checked by electrical testing of the coupon. However, such electrical testing just gives one the health status of the interconnects in terms of their resistance value. It does not give any further information about the kind of failure (e.g. microcracks, separation between the base of the micro-via and the target pad, barrel cracks, corner cracks, circumferential cracks). The cooperation between AT&S and MCL addresses a detailed and improved failure analysis.

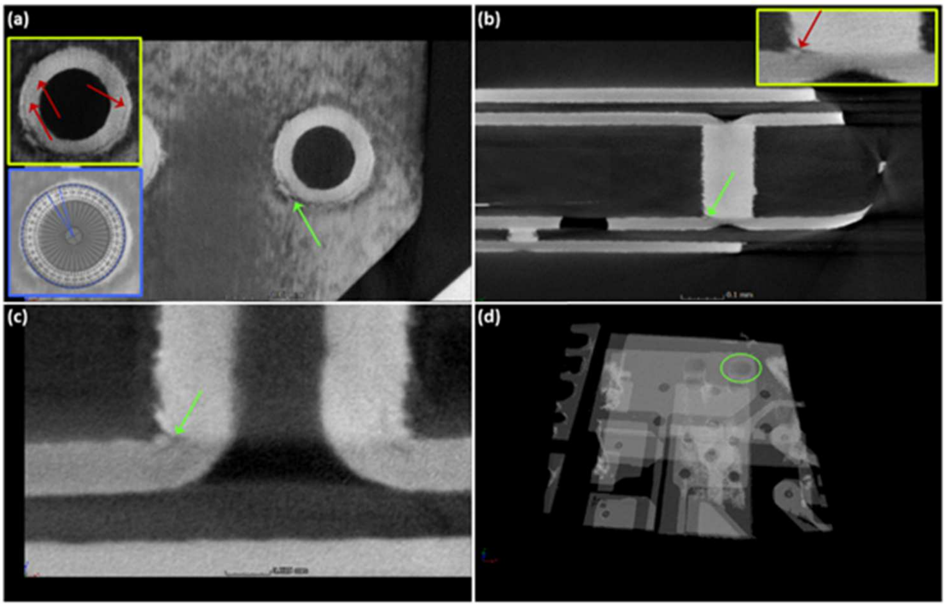


Fig. 6.1: Three-slice view: (a) top view, (b) side view, (c) front view, and (d) 3D overview for a better orientation. In (a), the via contains circumferential cracks. The crack appears to run over most of the full 360° (see image insert in (a)). (b) shows that the crack runs into the metallization below the via.

One used characterization method is X-ray Computer Tomography (CT), which enables three-dimensional mapping of the cracks (see Fig. 6.1). To localize and specify identify materials, Electron Beam Absorbed Current (EBAC) was used. The method takes advantage of the interaction between the electron beam of the SEM with the conductive material, to reveal further information about the material under test. The electron beam injects charges and they are absorbed by the metal, this, in turn, induces a current which is measured by a probe (in our case a conductive AFM tip). The obtained image reveals less conductive regions in terms of change in the resistance and localizes short or opens. However, this requires a prior rough localization of defects to place the cross-section of the microvia on the spot of interest. This place is obtained by the CT presented above. The combination of both techniques the CT and the EBAC provides a powerful technique to characterize Cu vias in PCB boards.

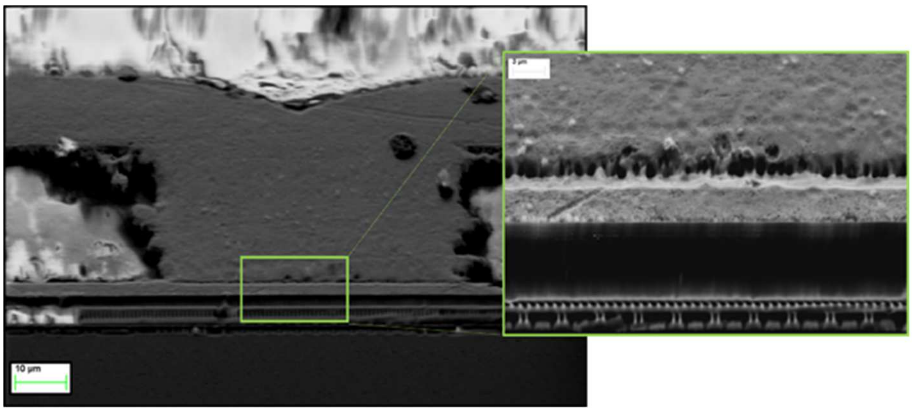


Fig. 6.2: EBAC image of a cross-section of a micro-via. There is a crack between the Cu via and the plated Cu – on that plated Cu there is a less conductive region (brighter region).

Fraunhofer ENAS

SENSITEC MAGNETORESISTIVE SENSORS

#7. Investigation of production related thermo mechanical effects for a current sensor device (IP-17)

As an important part of a current measurement module, a special SO16 current sensor was developed by Sensitec GmbH with molded System-in-Package design. Consisting of an anisotropic magneto resistive sensor, two magnets and one ASIC it passes several process steps during manufacturing and is exposed to different temperature loads (see Fig. 7.1). Due to different thermal expansions of the package materials (CTE mismatch) and the time/temperature dependent viscoelastic behavior of the molding compound, several different thermo-mechanical loading situations occur until the end of the manufacturing process. Therefore, the intrinsic strain distribution at the anisotropy magnetic resistive (AMR) sensor surface with its sensor cells changes permanently along the process chain. This can lead to a possible manifestation of a calibration inaccuracy and consequently to a certain measurement deviation of the sensor device, caused by a drift of its offset voltage. The final product quality is therefore directly affected by thermo-mechanical effects during processing.

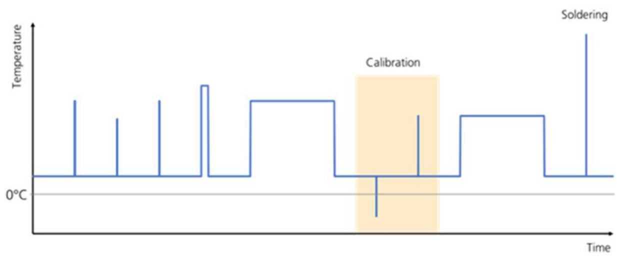


Fig. 7.1: Temperature dependent scheme for the production process.

Fraunhofer ENAS has built a virtual prototype model of the SO16 sensor device where relevant nonlinear and temperature dependent material descriptions like metal plasticity and viscoelasticity were included. Furthermore, the non-standard lead frame design with its comb like structure was also part of the virtual investigations as it was one reason for the non-trivial strain distribution near the surface of the AMR sensor. To investigate the influences of fluctuating material properties like Young's modulus and coefficient of thermal expansion (CTE) an extensive Design of Experiments study with in sum 41 process and material related parameters was conducted. This enabled the quantification of uncertainties and their impact on the sensor behavior (see Fig. 7.2.)

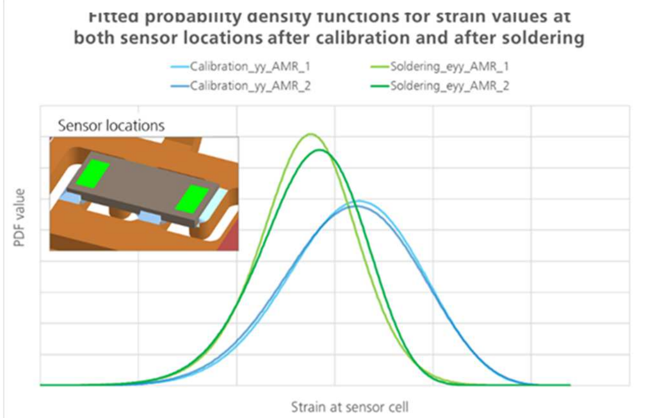


Fig. 7.2: Fitted probability density function for the strains extracted from the DoE study after calibration and soldering.

With the usage of industrial state-of-the-art meta-modeling algorithms, a massive shrinkage of the initial input parameter space of 41 parameters to a significant smaller number was possible (Fig. 7.3). It is obvious that most of the process related parameters vanished and the mold compound plays an important role for the resulting strain values at the AMR sensor surface. Furthermore, due to the generation of the lightweight meta-model a fast prognosis for the strain values is now possible and enables the assessment of the SO16 sensor package for different parameter configurations within seconds.

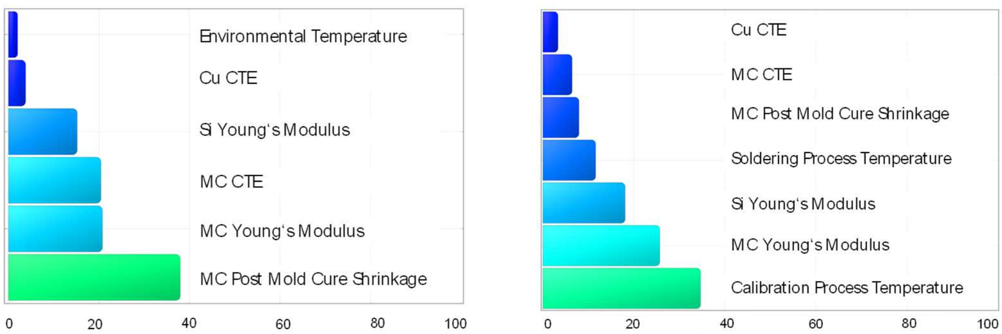


Fig. 7.3: Most influential parameters for the absolute strain values after soldering (left) and the strain difference between soldering and calibration (right) shown as coefficient of prognosis [%].

#8. Investigation of element enrichment in silicone gels used to encapsulate inverter modules for renewable power generation (IP-17)

In application like renewable energy production or transportation power electronics can be exposed to high relative humidity levels, which can lead to early failures. Therefore, power electronic devices are tested for reliability under harsh conditions during development. To shorten testing times aging processes are accelerated by applying temperature and humidity levels which exceed the typical use conditions by far. But the aging a device will undergo within the years or decades of its lifetime is complex and not all relevant processes will be accelerated on the same timescale during testing. As a result, certain aspects might be under or over tested. By comparing changes in devices taken from the field with devices after testing these aspects could be identified and test protocols optimized.

The focus of a first study presented in March 2022 at CIPS 2022 in Berlin was to investigate the enrichment of impurities within silicone gels protecting power electronic modules. These impurities are of interest, as depending on their type they might either be a result of corrosion processes or lead to a reduced reliability e.g. by accelerating corrosion or influencing the insulation properties of the silicone gel.

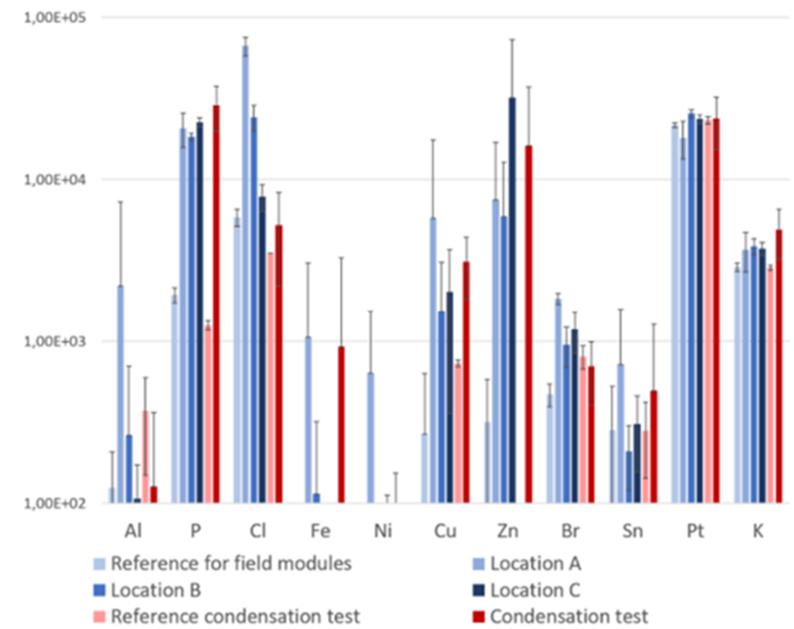


Fig. 8.1: Overview of the element content in silicone gels taken from the different power modules.

In this study power modules of three photovoltaic string inverters installed at different locations and after an operation time of 7.5 years were compared with modules of an inverter tested in a continuous condensation test for 78 days and the respective reference modules. Element content was compared using inductively coupled plasma mass spectrometry (ICP-MS). Compared to the reference modules the field modules as well as the test modules showed an increase of some elements. Potential sources for the impurities were investigated and were presented in detail at CIPS 2022. A difference in enrichment of certain elements was found between test and field modules. The content of chloride and bromide was increased within the silicone gel coating of field modules but did not show an enrichment for modules that ran the continuous condensation tests. The differences in halide content are of interest as halides are known to play an important role in corrosion processes. As a result, it is possible that under the chosen test condition the influence of halogenides on the corrosion behavior was not considered. Therefore, the continuous condensation test did not fully represent the loads that are exerted on the modules by the environmental conditions in the field.

A deeper knowledge on the behavior of power electronic components and their material degradation processes in use will lead to a better understanding of complex failure mechanisms. Further studies on this topic are planned to gain a deeper understanding on the mechanisms of element enrichment in silicone gels and their possible influence on the reliability behaviour.

DISSEMINATION

Scientific results were published in book chapters, during international conferences and journals publications

Books

3 book chapters in "Reliability of Organic Compounds in Microelectronics and Optoelectronics", ed. W. D. van Driel and M. Y. Mehr, Springer, 2022. ISBN 978-3-030-81575-2, DOI: 10.1007/978-3-030-81576-9:

- "Reliability and failures in solid state lighting systems", pp. 211-240
- "Outlook: From physics of failure to physics of degradation", pp. 535-538
- "Reliability and Degradation of Power Electronic Materials", pp. 449-478

Outlook: A book on innovative results on reliability from iRel40 is under preparation

Conference Contributions

44 presented and 19 planned conference contributions and presentations for "31st European Safety and Reliability Conference (ESREL)", "IEEE 8th Workshop on Wide Bandgap Power Devices and Applications (WIPDA)", "2021 IEEE International Electron Device Meeting (IEDM 2021)", "2021 IEEE International Integrated Reliability Workshop (IIRW)", "IEEE International Conference on Connected Vehicles and Expo 2022 (ICCVE2022)", and others. The list of published conference contributions is available on the project webpage *www.iRel40.eu*.

Published journal articles

1. Olschewski, T., "*Fast Accurate Defect Detection in Wafer Fabrication*", arXiv preprint, arXiv:2108.11757 (2021).
2. Millesimo, et al., "*High-Temperature Time-Dependent Gate Breakdown of p-GaN HEMTs*", IEEE Trans. on Electron Devices 68, no. 11 (2021): 5701-5706.
3. Tallarico, et al., "*TCAD Modeling of the Dynamic V TH Hysteresis Under Fast Sweeping Characterization in p - GaN Gate HEMTs*", IEEE Trans. on Electron Devices 69, no. 2 (2021): 507-513,
4. Olschewski, T., "*Defect Detection on Semiconductor Wafers by Distribution Analysis*", arXiv pre print, arXiv:2111.03727 (2021).
5. Safari, L. et al., "*Towards Realization of a Low-Voltage Class-AB VCII with High Current Drive Capability*", Electronics 10, no. 18 (2021): 2303.
6. Van Driel, W. D., et al., "*Reliability of LED-based systems*", Microelectronics Reliability 129 (2022): 114477.
7. Meneghini, M., et al., "*GaN-based power devices: Physics, reliability, and perspectives*", J. Appl. Phys. 130, no. 18 (2021).
8. Bonet, F., et al., "*Carrier Concentration Analysis in 1.2 kV SiC Schottky Diodes under Current Crowding*", IEEE Electron. Dev. Letters 43, no. 6 (2022).
9. De la Rosa, Francisco López, et al., "*Geometric transformation-based data augmentation on defect classification of segmented images of semiconductor materials using a ResNet50 convolutional neural network*", Expert Systems with Applications (2022): 117731.
10. Hagara, Miroslav, et al., "*Modified algorithm of unimodal thresholding for FPGA implementation*", Microprocessors and Microsystems 94 (2022): 104669.

Published journal articles — continue

11. López de la Rosa, Francisco, et al. A review on machine and deep learning for semiconductor defect classification in scanning electron microscope images. Applied Sciences 11.20 (2021): 9508.
12. Modolo, N., et al. Compact Modeling of Nonideal Trapping/Detrapping Processes in GaN Power Devices. IEEE Transactions on Electron Devices 69.8 (2022): 4432-4437.
13. De la Rosa, Francisco López, et al. A deep residual neural network for semiconductor defect classification in imbalanced scanning electron microscope datasets. Applied Soft Computing (2022): 109743.

Combining advanced metrology, process control and surface processing – Next level for reliability?!

In achieving challenging goals in reliability of semiconductor products and processes, connections between metrology, advanced data analysis and process control are an essential prerequisite. In order to enhance dialogue and collaboration, iRel40 partners WHZ and FhG-IWS (lead by Christopher Taudt) have published a call for papers for a special issue in the journal Metrology (MDPI) named "Next Level Surface Metrology—Towards Photonic Metrology and Surface Processing" (Fig. 9.1).

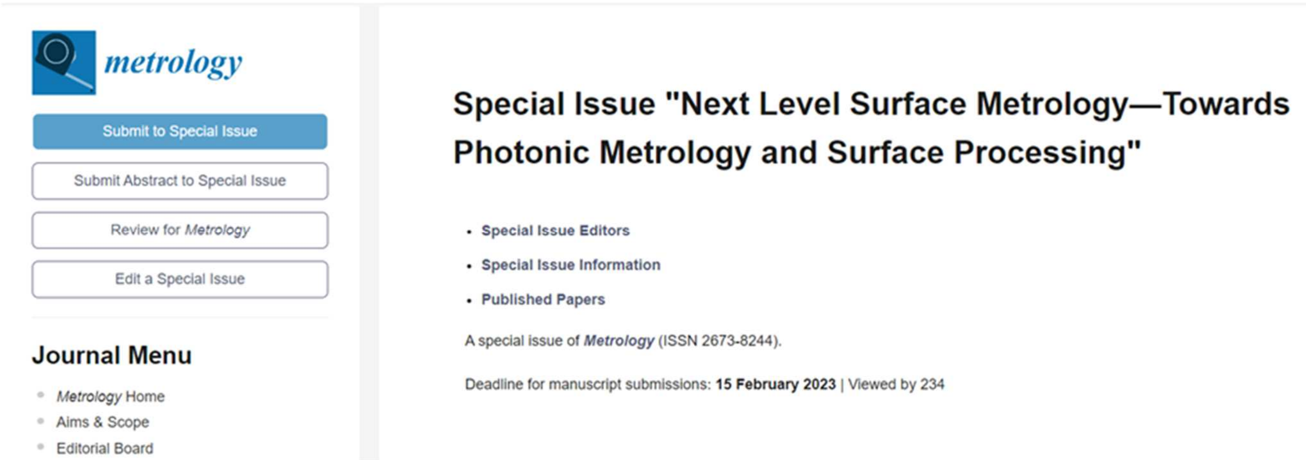


Fig. 9.1: Screenshot of the open call for the Special Issue in the Journal "Metrology" (MDPI).

This special issue will encourages researchers with backgrounds in optical metrology, image processing, (photonic) surface processing and closed-loop process control to communicate their research and how it can leverage potential by combining these often separately research disciplines. Especially, a variety of fields, such as novel sensing approaches, intelligent data processing techniques, as well model-based manufacturing schemes are going to be discussed alongside or at best in combination with each other.

In terms of iRel40, these are the key elements to enhance reliability in order to bring it to a new level in complex production environments. By means of this Special Issue, members of the consortium are encouraged to submit key results from the project while they are put into context with the scientific community outside of the project. This should enable a meaningful discussion and bi-directional exchange of ideas. Beside pure dissemination of results, it is anticipated to also learn from related scientific work outside of the project across the disciplines of physicists, laser engineers, data processing experts, and system theorists.

Link: https://www.mdpi.com/journal/metrology/special_issues/5EG8B2F36V

iRel40 results presented at EuroSimE 2022

The 23rd International Conference on Thermal, Mechanical and Multi-Physics Simulation and Experiments in Microelectronics and Microsystems took place in Malta between 25th and 27th of April 2022. More than 120 participants discussed their latest results on the topic and impact on reliability improvement. It was one of the first events that were held F2F with an exemption of 1 on-line session only. Lively discussions during the breaks extended almost every session as it was so great to meet each other after being on-line for 2 full years.

In 2022 the EuroSimE Technical Committee made substantial effort to bring an exciting F2F program together. This program finally included:

- 16 sessions comprising of oral and poster presentations
- 5 short courses given by distinguished speakers from industry and academia
- IEEE Heterogeneous Integration Roadmap (HIP) update
- Research updates from European Union funded projects

Extensive opportunities were offered for technical exchange between participants and exhibitors of computer simulation software and characterization equipment.

Fig. 10.1: Presentation of Martin Niessner (Infineon).

The iRel40 project contributed with several papers and presentations to the program. The iRel40 project was introduced by Willem van Driel, who presents Signify in the iRel40 project and is the chair of EuroSimE, in a session on European funded project. The importance of reliability improvement for Europe was highlighted.

The following three iRel40 contributions were presented during EuroSimE 2022:

In chapter 4 on "Reliability and life time simulation" Maofen Zhang et al. from Infineon presented their iRel40 paper on *"Investigation of the impact of thermal aging of molding compounds on the solder joint fatigue of a VQFN package"*.

In chapter 6 "Dialog session (poster)" R. Kniely et al. from ams-OSRAM presented their iRel40 related paper on "Characterization of interfacial parameters for lifetime modeling in modern optical sensor package assemblies". In chapter 9 "Advanced Simulation Techniques" Markus Frewein et al. from AT&S presented their iRel40-related paper entitled "An advanced, systematic simulation approach for studying warpage drivers of an assembled printed circuit board in early development stage". TU Delft presented their work on modeling the thermal degradation of plastics and in-situ reliability monitoring of power packages.

An additional contribution of work in iRel40 was presented during the Heterogeneous Integration Roadmap (HIR, https://eps.ieee.org/technology/heterogeneous-integration-roadmap.html) session. Since its 2021 version the HIR has an own chapter on Reliability. During their roadmap discussions the HIR experts identified reliability as a major topic and decided to set-up an own chapter in addition to the already existing chapters. Members of the iRel40 team are important contributors to this HIR chapter, e.g. Bosch. Signify, Infineon, Fraunhofer etc. Martin Niessner from Infineon presented an iRel40 related contribution on *"Impact of Production Quality on Product Reliability"* (see Fig. 10.1). This presentation also included the importance of the link between the ECSEL JU project iRel40 and the IPCEI for ME in respect to advanced manufacturing.

iRel 4.0
intelligent Reliability 4.0

iRel40 results presented at EuWoRel 2022

The EuWoRel (European Workshop on Reliability) is an annual reliability expert workshop with usually 30-35 invited participants. The workshop is organized as an activity of EPoSS, the European Technology Platform on Smart Systems Integration, by Fraunhofer ENAS, IMEC, and RISE. In 2022 the workshop took place at 8th/9th of September at the Fraunhofer Forum at Berlin. Participation at this event is by invitation only. Participants are typically from European application industry, like in 2022 Thales, Mercedes, Cariad, from semiconductor and assembly and package industry, like in 2022 Infineon, Bosch, XFAB, AT&S, amsOsram, Murata, OnSemi, Ericsson, and research centers like in 2022 Sirris (BE) and IRT-Saint Exupery (FR) in addition to the workshop organizers. The EuWoRel event focuses on future work to improve design and test efficiency for best product reliability of electronics made in Europe. The two days meeting covered a total of 22 contributions as well as 3 interactive sessions generating input to the EU research policy makers. The iRel40 project had a focus session with four expert contributions as well as two presentations in regular sessions.

Fig. 11.1: The iRel40 project leader Klaus Pressel (Infineon) introduced the iRel40 project. He presented the importance of the bathtub curve and showed examples on design for reliability improvement in assembly and packaging like device tracking and equipment stability.

Thomas Krivec (AT&S) introduced the work of AT&S on their industrial pilot where they develop virtual prototyping environment for their innovative laminate substrate technologies. Sonja Crocoll (XFAB) demonstrated the status of their work on Design for reliability and their work methods and applications. Shaitra Harsha (Sirris) showed first results of their work in iRel40 on data driven models to estimate delamination progress.

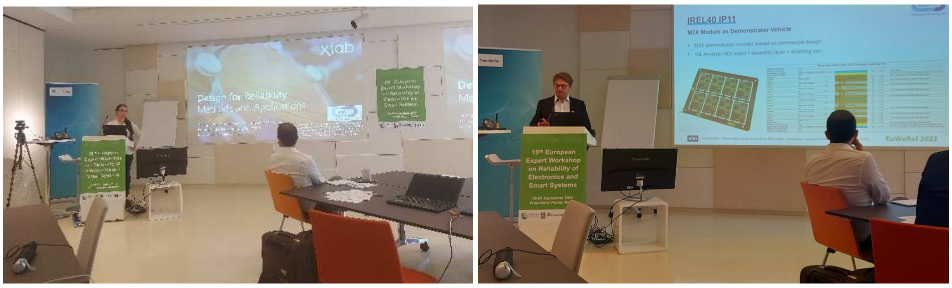


Fig. 11.2: Presentation of Sonja Crocoll XFAB (left) and Thomas Krivec AT&S (right).

Two more iRel40 presentations were given in the regular sessions. Andreas Lövberg (RISE) presented results on machine learning for prognostics of power electronics. Martin Niessner (Infineon) gave a presentation on “Simulation of Power Cycling on Board (PCoB) and lifetime estimation via metamodel app”. In Addition three key members of the iRel40 project Dag Andersson (RISE), Sven Rzepka (ENAS) and Bart Vandeveldte (IMEC) moderated the event. Thus, the iRel40 project contributed strongly to this workshop.

The EuWoRel 2022 workshop allowed fruitful exchange between reliability experts, which come from various domains of the value chain. For the iRel40 participants it was interesting to get feedback from the community to further strengthening their research!

iRel40 results presented at ESTC 2022

The ESTC (Electronics System-Integration Technology Conference) is one of the leading conference on assembly and packaging in Europe. Main focus is on latest package developments related to system integration. The 9th ESTC 2022 took place in-person in Sibiu (Romania) between 13-16th September, 2022.

The iRel40 leadership team organized a Workshop entitled "iRel40 – Intelligent Reliability along the Value Chain". The iRel40 project was introduced and selected project results on reliability improvement were presented. After a 10 minutes introduction of the project by the project leader Klaus Pressel in four presentations selected important project results were presented:

The first presentation was on intelligent manufacturing, the second on innovative testing, the third on development towards virtual prototyping, and the fourth on artificial intelligence applied to image detection. Target of all four topics was on research and development applying Artificial Intelligence, Digital Twins and Machine Learning concepts for reliability improvement. Following 4 contributions were presented during the iRel40 special session:

- ***Intelligent Manufacturing – From the Chip – Package – Board/System: Impact on reliability*** by Klaus Pressel and Josef Moser from Infineon
- ***Holistic Testing in iRel40 and Impact on Reliability*** by Susan Zhao from Signify
- ***Virtual Design for Life Time optimization of M2X Modules – A Use Case from the iRel40 project*** by Thomas Krivec from AT&S
- ***AI applied to CSAM Images*** by Jason Zi Jie Chia from Elmos Semiconductor

In addition, further three iRel40 contributions with papers contributed to regular sessions: i) *"SAC305 solder fatigue crack propagation under 3-point bending cycle test condition"* by M. Zhang from Infineon Technologies AG and project partner TU Chemnitz (both Germany); ii) *"Improving the production quality and robustness of a SO16 sensor package by a simulation based digital twin approach"* by H. Möller from Fraunhofer Institute for Electronic Nanosystems (ENAS) and Sensitec GmbH (both Germany) and iii) *"Deformation measurement on cross sections of Fan-Out Wafer Level Package by Digital Image Correlation (DIC)"* by I. Maus from Infineon Technologies AG, Germany.

Fig. 12.1: (left) iRel40 presenters at the ESTC 2022, (right) the conference chairman Paul Satka with Josef Mosef and Klaus Pressel.

iRel40 results presented at IEEE IECON 2022

The 48th Annual Conference of the IEEE Industrial Electronics Society (IECON 2022) took place in Brussels between 17-20 October 2022. Dr Barış Bulut of Enforma, an iRel40 consortium partner, was the co-organiser of the session entitled ***"SS20 Predictive analytics architectures and applications for industrial systems – 2nd edition"***.

The session held particular significance for iRel40 members as the session addressed two of the five main technology clusters intrinsically defined by the project's 34 use cases, namely **"AI based control systems in advanced production"** and **"Prognostic and Health Management / digital twin / condition monitoring"**.

Among the 9 papers accepted for the special session, the following 4 papers were from iRel40 partners:

- ***On Suitability of the Customized Measuring Device for Electric Motor*** by Rok Hribar[1], Gašper Petelin[1], Margarita Antoniou[1], Anton Biasizzo[1], Stanko Ciglarič[2], Gregor Papa[1]
- ***An AI-based Architecture Framework for Improving End-of-line Reliability Tests of Electric Motors*** by Mujdat Soyturk[3], Kutalmış Coşkun[3], Onur Izmitlioglu[3], Borahan Tümer[3], Deniz Güneş[4], Sinan Saraçoğlu[4], Barış Bulut[6], Hasan Burak Ketmen[6], İsmethan Hanedar[7], Taşdemir Aşan[7], Eray Aydın[7†]
- ***Investigation of Potting Compounds on Thermal-Fatigue properties of Solder Interconnects*** by Leiming Du[8], Xiujuan Zhao[9], Piet Watte[9], Rene Poelma[10], Willem Van Driel[8,9], Guoqi Zhang[8]
- ***Data-Centric Model Development to Improve the CNN Classification of Defect Density SEM Images*** by Corinna Kofler[11], Claudia Anna Dohr[12], Judith Dohr[12], Anja Zernig[11]

[1]Jozef Stefan Institute (SI), [2]Elaphe (SI), [3]Marmara University (TR), [4]Arçelik (TR), [4†]Wat (an Arçelik company) (TR), [6]Enforma (TR), [7]Pavotek (TR), [8]Delft University (NL), [9]Signify (NL), [10]Nexperia (NL), [11]Kai (AT), [12]Infineon (AT)

These papers successfully engaged 11 of the 75 iRel40 partners, located in 4 of the 13 countries.

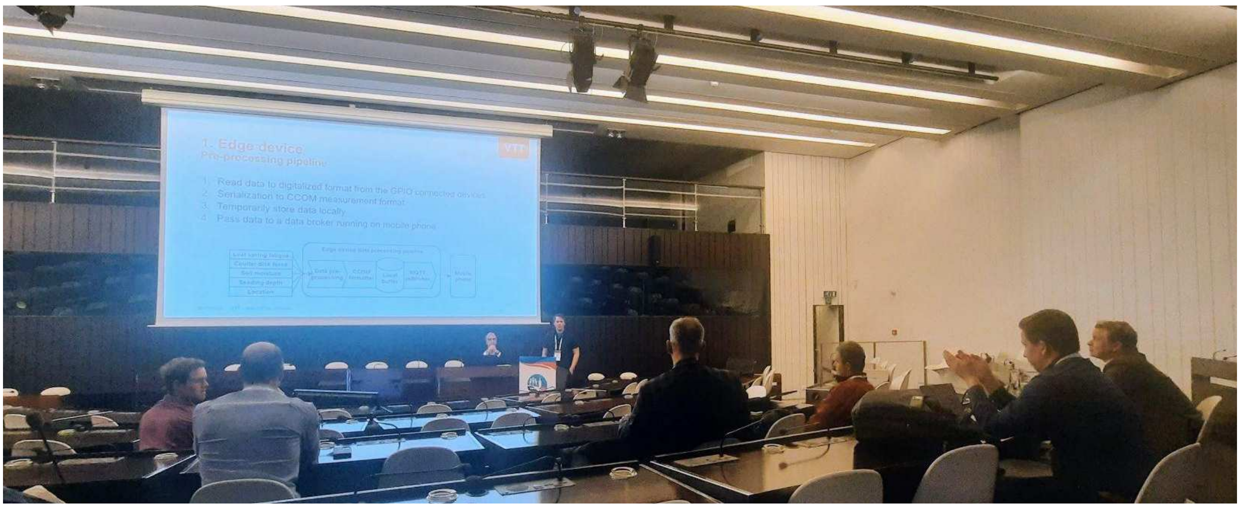


Fig. 13.1: iRel40 presentation at IEEE IECON 2022.

iRel40 results presented at IEEE ASDAM 2022

The 14th International Conference on Advanced Semiconductor Devices and Microsystems (ASDAM 2022) took place at Smolenice Castle, Slovakia between 23-26 October 2022. STUBA, an iRel40 consortium partner, was the co-organiser of the session entitled ***"ECSEL JU project iRel40 workshop ".*** This session was in a close connection with the special session focused on IPCEI Workshop organised in cooperation with Infineon Technologies Austria AG.

The session presented an overview of selected results from the ECSEL JU project iRel40 with a focus on the improving reliability of electronic components and systems by mission profile cycling procedure, reduced internal stress of die attached for power components, and by improving robustness of GaN circuits against corrosion by polymer coatings.

Following 4 papers were presented during the iRel40 special session:

- ***Reliability along the Value Chain - from Chip to Board/System (Invited lecture)*** by K. Pressel[1] and J. Moser[2]
- ***A Multi-Channel System for Active Thermal Cycling of Discrete Power Semiconductors Based on Mission Profiles*** by D. Kostynski[3], S. Sack[2], P. Kolter[3], M. Glavanovics[3]
- ***Low-temperature die attach for power components: Cu-Sn-In solid-liquid interdiffusion bonding*** by F. Emadia[4], S. Liua[4], A. Klamia[4], N. Tiwarya[4], V. Vuorinena[4], and M. Paulasto-Krockela[4]
- ***Polymer Coatings for Better Robustness of GaN-based RF Circuits against Corrosion in SiP*** by G. Bellomonte[5], B. Atawa[6], A. Serghei[6], N. Michel[5], N. Delpuech[5], M. Oualli[5], Q. Levesque[5], J.C. Jacquet[5], S. Piotrowicz[5], E. Molina[6], H. Stieglauer[7], B. Lambert[8], Ch. Brylinski[6], and S. L. Delage[5]

[1]Infineon Technologies (DE), [2]Infineon Technologies (AT), [3]KAI Kompetenzzentrum Automobil und Industrielektronik (AT), [4]Aalto University (FI), [5]III-VLab (FR), [6]UCBL (FR), [7]UMS (DE), [8]UMS (FR).

These papers successfully engaged 7 of the 75 iRel40 partners, located in 5 of the 13 iRel40 countries.

Fig. 14.1: iRel40 participants at ASDAM 2022.

General Assembly Meeting

Ljubljana, November 7-10th, 2022

intelligent Reliability 4.0

The second F2F General Assembly meeting of the ECSEL JU project iRel40 took place in Ljubljana (Slovenia) between 7th-10th of November 2022. The three-day meeting was hosted by the iRel40 partner JSI. About 90 participants joined the event in Ljubljana. During the General Assembly, the status of the iRel40 project was summarized and interesting technical presentations were given. Figure 15.1 shows the iRel40 partners participating at the F2F meeting.

Fig. 15.1: About 90 participants joined the General Assembly meeting onsite.

On the first meeting day, the focus was on the project status, the feedback and recommendations of the 2nd year review as well as next steps and decisions to be taken for the last project year. The project status included also an overview of the six still-active work packages, given by the WP leaders. This part of the General Assembly was set as a hybrid meeting in order to give also the partners not-present on-site the opportunity to be informed of the project status. The following eight technical workshops were not performed in hybrid mode, to better focus on the technical exchange and discussions.

The technical workshops were prepared by different iRel40 experts, active in the technical work packages WP2 to WP6. The workshops started with the iRel40 use cases and industrial pilot's status and progress, accompanied by a poster session (WP6). The two workshops from WP2 focused on artificial intelligence as well as digital twins and their impact on reliability. One workshop concentrated on physics of failure, organized by WP2 and WP3. The workshop of WP4 dealt with intelligent manufacturing topics and WP5 concentrated in its workshop on the importance of KPI for testing. Two further workshops were organized by WP3 dealing with material simulation topics and the test vehicles gathered in iRel40. During the workshops fruitful discussions took place. The Figure 15.2 shows the WP5 panel discussion on the importance of KPIs for testing.

Fig. 15.2: A lively panel discussion during the WP5 workshop.

The ongoing work of the partners within the use cases was also presented with the dedicated posters, where we could check the progress in the last period. Figure 15.3 (left) shows the setting of 34 posters in the meeting room, where the discussions also took place. iRel40 supports the involvement of young scientists in research activities within the project. Figure 15.3 (right) shows 4 young colleagues with their technical posters.

Fig. 15.3: (left) Meeting room filled-up with posters of use-case presentations, (right) 4 young scientists in front of technical posters*.*

The meeting at Ljubljana demonstrated the importance of fruitful discussions between project partners of different domains. Technical terms like digital twin and artificial intelligence were discussed in the context of reliability. In the iRel40 project partners from the whole semiconductor value chain are participating from wafer production, chip manufacturing, assembly and packaging, board/system competence and applications, also including different domains like informatics, mathematics, material physics as well as modelling and simulation.

More information on the 2nd F2F General Assembly can be found on www.iRel40.eu

iRel40 presented at EFECS 2022

The European Forum for Electronic Components and Systems (EFECS) is the international forum to create impact by collaborative innovation! The focus during 2022 was on an autonomous and sustainable Europe along the Electronic Components and Systems value chain in Europe. The organizers of this event, AENEAS, EPoSS, and Inside, joined forces to bring all stakeholders together on 24-25 November 2022 in Amsterdam at Beurs van Berlage (see www.efecs.eu).

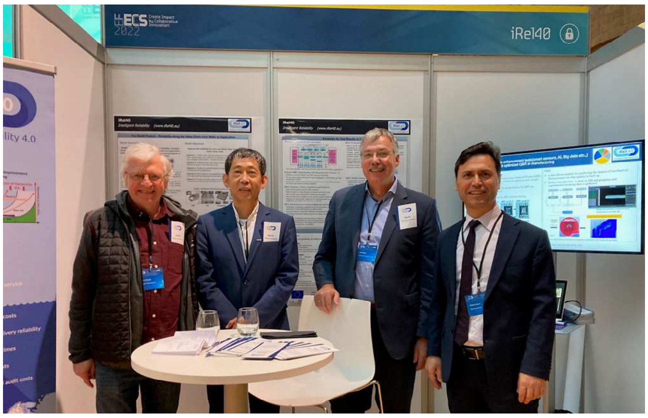


Fig. 16.1: Part of the iRel40 booth team at EFECS 2022.

During the EFECS event, all major European-funded projects presented their work including achieved results. It is an excellent platform to exchange ideas and to catalyze collaboration. The iRel40 team for example had an especially exchange with the Eureka Penta/Euripides project FA4.0, with the ECSEL JU projects Twilight and HiEFFICIENT, which cover complementary topics. For example with HiEFFICIENT, a common conference workshop in 2023 has been agreed upon. At EFECS 2022 the iRel40 project was presented by a poster booth. For the booth, the iRel40 roll-up, which highlights the bathtub curve, two poster pages, as well as a slide series that presented iRel40 highlights on a LED screen were prepared. Figure 16.1 shows a part of the poster crew, and Figure 16.2 shows the project flyer that presents a brief but key project information.

An important topic discussed at EFECS was the lack of young academics with special emphasize on the low involvement of young women in natural sciences and microelectronics. The topic of missing young academics is also an issue tackled by the iRel40 project. During the conference workshops, iRel40 tries to motivate young scientists. One recent example was the ASDAM 2022 conference (see page 17) co-organized by iRel40 project partner STUBA which especially provides a platform to young scientists.

Fig. 16.2: iRel40 flyer that presents project and achieved results.

The iRel40 project supported the ASDAM 2022 with a workshop and created a link to the IPCEI project. In addition, iRel40 encourages young scientists to present their latest results by posters or presentations during the F2F meetings. This was a very successful technical contribution to the first two iRel40 F2F meetings in Istanbul (see M24 newsletter) and Ljubljana (see this newsletter, page 18ff). Several key iRel40 partners (MCL, IMEC, Fraunhofer, TU Delft, Bosch) submitted a Marie Curie Doctoral Networks proposal (Call: HORIZON-MSCA-2021-DN-01), named MIRELAI; This proposal with the full title MIcroelectronics RELiability driven by Artificial Intelligence has been accepted in April 2022. 13 PhDs will be shared between the above-mentioned iRel40 partners, which will strengthen the pan-EC network idea driven out of iRel40 (see www.mirelai.eu).

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