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Reliability:Past and Present

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Chapter 1
Reliability: Past and Present

W. D. van Driel, K. Pressel, and M. Soyturk

"The times they are a-changin'"; that is what Bob Dylan's song is about. And that is also what iRel40 is about. We are at the doorstep of major changes in reliability concepts. Simple FIT (Failure In Time), MTBF (Mean Time Between Failure), and MTTF (Mean Time To Failure) concepts as well as standard-based component quality testing will become history in the future. Physics of failure, although a very strong concept, will see further improvements as well, like Dylan sang, "As the present now will later be past."

The history of reliability as we know it now goes back to the 1950s, when electronics started to play a major role for the first time [1]. Now, seven decades later, with million times more complex electronic systems, the industry is facing a continuous increase of early and wear-out failures with accompanying consequences. Nowadays, products with high failure rates may come under public scrutiny due to negative customer feedback publicly shared on websites, eventually building bad reputation for a company [2]. To cover the increasing demands in product reliability performance, three distinct waves can be noted [3]:

- Wave 1: Stress Based

The first wave was characterized with the establishment of a test-to-failure approach based on standardized stress-based tests. Examples are thermal cycling, moisture testing, and/or operational tests under combined conditions. Each of these

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tests got standardized in the semiconductors industry by dedicated bodies, like JEDEC, IEEE, or IEC [4, 5], to enable smooth comparison between suppliers and test houses. Understanding of possible failure modes gradually increased in several industries using semiconductor devices, but the use of prediction models was still limited.

- Wave 2: Knowledge Based

The second wave continued from all the test results obtained over a period of 30–40 years in the first wave. Companies started to understand the physics that caused failure modes in their products. Test schemes changed to test-to-failure instead of test-to-pass. Still standardized tests are used under the condition of similarity: if a previous product differed slightly from a new one, no new testing was required. This wave is characterized as knowledge-based qualification [6]. Models became commonly used in this wave both analytical and numerical (using finite element methods) ones. One new ingredient was introduced: structural similarities. To efficiently select qualification and reliability monitoring programs, structural similarity rules for integrated circuit designs, wafer fabrication processes, and/or package designs are successfully used by the industry. By following the package structural similarity rules, the numbers of reliability qualification tests (and thus costs) are greatly reduced [7, 8].

- Wave 3: Application Based

In the third wave, application conditions are considered. All industries performed a substantial amount of application studies in which dedicated sensors are used to measure the actual loading, in terms of temperatures, vibrations, and/or external forces. Here measure, in some cases, means monitoring so that the data is logged continuously and sent to an online database. Standards got available [9] and some bodies published guidelines [10]. Still, a substantial amount of debate on the actual application conditions in several application areas is ongoing.

As of today, most industries are in the transfer from wave 2 to wave 3. Semiconductor strategies currently are to determine the reliability capability by applying (where possible) the test-to-failure concept, extending reliability qualification conformance tests beyond the required levels, and assessing any physical or electrical degradation of a product during those tests. For the building blocks or complete products, the reliability capabilities are evaluated with a set of conformance tests related to specific application areas. The tests and their requirements are defined by using knowledge of potential failure modes and rules for structural similarity. These rules and tests can be used to qualify derivatives of released building blocks. For new failure modes and new or modified acceleration models or model parameters, the applicability of conformance test requirements and structural similarity rules are then updated (Fig. 1.1).

Wave 3 goes hand in hand with the current development of machine learning, digital twin driven diagnostics or prognostics, and health monitoring [8]. These technologies are needed to move to *wave 4: physics of degradation and robustness*

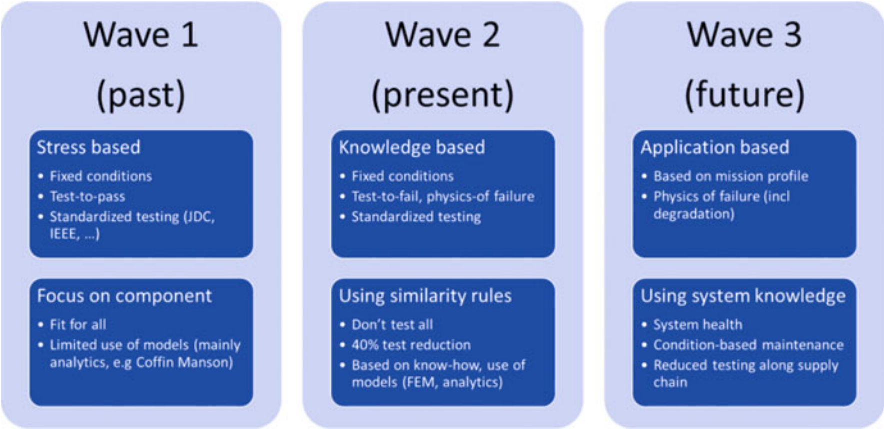

Fig. 1.1 Waves in reliability

validation. These two new concepts will become available at a significant level of maturity.

1.1 Physics of Degradation

Degradation is apparent in all things and is fundamental to both manufactured and natural objects. It is often described by the second law of thermodynamics, where entropy, a measure of disorder, tends to increase with time in a closed system. Simply said things age. The natural ageing and degradation of materials has been a subject of study by engineers and scientists for many, many years. But, with the demands placed on new engineered materials and devices for electronics, computing, aerospace, and biomedical applications, the reliability of such over time has become more and more crucial [11, 12].

Degradation is apparent in naturally occurring materials and structures as well as human-engineered materials and devices. In everyday experience, it is the ever-present phenomena of spontaneous loss of some quality, functionality, and order. Work must be done from outside the system of interest to maintain that functionality, or that order. The second law of thermodynamics formally captures this idea with the concept of entropy or disorder, which states [13]:

> During real processes, the entropy of an isolated system always increases. In the state of equilibrium, the entropy attains its maximum value.

This loss of order or degradation has many terms or phrases to label the phenomena, such as ageing, deterioration, devolution, and wear-out. It is this degradation in electronics that this book has explored.

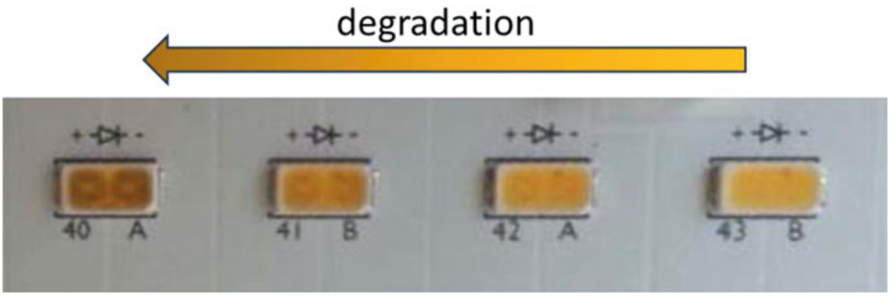

Fig. 1.2 Visible degradation in LEDs: corrosion of the silver layer

The mechanisms of degradation for a variety of materials and structures cover a wide range of discipline categories such as thermal, mechanical, chemical, biological, and so on. All associated degradation mechanisms require the knowledge and understanding of natural processes and thus are grouped together as the physics of degradation. As mentioned above, the fundamental underlying principle is entropy and the second law of thermodynamics. Health monitoring [14] and/or digital twin technologies [14, 15] may support the engineers to understand, master, and forecast the physics of degradation. The concept of digital twin is relatively new. It was conceptualized during the early years of the twenty-first century and has gained traction mainly during the last decade. The primary reason behind it is the further digitalization of the electronic industry, which has been accelerated by the newly emerging IT technologies. Digital twin enables system optimization, monitoring, diagnostics, and prognostics using integration of artificial intelligence, machine learning, and big data analytics. It can be used for predicting failures and estimating lifetime of electronic components, which then allows for scheduling preventive maintenance. Launching a preventive maintenance program like this allows company to save time and costs and avoid customer dissatisfaction as well as unwanted lawsuits.

An example of a visible degradation process is depicted in Fig. 1.2 [16]. This figure shows the corrosion of the silver layer inside an LED package due to the sulfur exposure. As time progresses, the silver layer turns black, and the light output of the device or product will be significantly reduced. Even the color will change from white to blue. Visibility is certainly not possible in semiconductor devices that have black molding compounds, and typically electronic parameters need to be measured, like resistance change and/or voltage drops.

1.2 Robustness Validation

Today's standard qualification procedures for electronic components, assemblies, and components for the automotive industry are based on the use of standardized tests at the end of the product development of parts and components. In contrast,

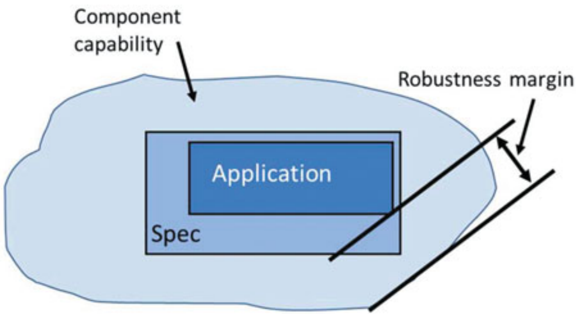

Fig. 1.3 Schematic illustration of the basic idea of robustness validation

robustness validation is a process that includes the entire product development process, as well as mass production. The qualification of the components based on the robustness analysis is thus implicit. The basic philosophy behind the robustness validation methodology is to gain knowledge about the size of the guard band by testing the semiconductor to failure, or end of life [17, 18]. The goal of the method is to achieve lower ppm failure rates by ensuring adequate guard band between the "real-life" operating range of the semiconductor and the points at which the semiconductor fails. The concept of robustness validation is relatively new. It was conceptualized during the early years of the twenty-first century and has gained traction mainly during the last 5–10 years. It found its origin in the automotive industry [19]. The new "test-to-failure" qualification approach (instead of a "test-to-pass") is a paradigm shift from "Fit for Standard" to "Fit for Application." Therefore, components could be designed with known robustness margins combined with cost- and time-saving potentials. The principle of robust validation is depicted in Fig. 1.3.

Robustness validation generates knowledge on the relevant component failure mechanisms that may occur at the boundaries of the specification limits [20]. Therefore, and as a result, components can be designed with known robustness margins combined with (quality) cost- and time-saving potentials. A note here is that although robustness validation focuses on a test-to-failure approach, it has the disadvantage of any concept that is using accelerated testing:

> Accelerated testing assumes that the degradation of products follows known laws (e.g., Arrhenius), which may not always be the case. Real-world conditions can be complex and nonlinear, making predictions less accurate.

It means that robustness validation should be combined with the monitoring of the product's and/or component's level of degradation.

1.3 The Fourth Wave

The abovementioned new concepts will be embraced in the fourth wave of reliability, physics of degradation, which will also reduce the amount (and cost) of product release testing. Progress in the area of reliability will never stop, and referring to

Dylan's lyrics, "Your old road is rapidly aging, please get out of the new one if you can't lend your hand for the times they are a-changin."

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