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Robustness Validation – A physics of failure based approach to qualification

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ABSTRACT

Product reliability is crucial to the success of a company. Product qualification today is based on standards that follow a stress-test driven approach, meaning pre-defined stress tests with pre-defined stress conditions. However, reliability requirements have increased, while at the same time both designs of semiconductor components and usage of these components in the applications have increasingly been pushed to the limits. This development raises the question, how far the standard procedures are still suitable for reliability assessment. Robustness Validation is an approach to a failure-mechanism-driven qualification that was primarily initiated by the automotive industry but has a much wider range of applicability. The paper will give an introduction to the basic ideas of Robustness Validation. Some limitations including statistical aspects will also be discussed.

1. Introduction

The advantages of electronics devices have led to their usage in many applications, even if these applications pose severe challenges regarding harsh environments and high reliability. Besides automotive, which is a prominent example, offshore windmills and solar energy are just two more examples, where both harsh environments and long lifetime requirements render reliability assessment a tough topic. The pressure to reduce costs and development cycle times in a competitive economic environment puts stringent boundary conditions on companies that all too often oppose what reliability engineers would see as reasonable procedures. Demands from functional safety that have arisen recently with the introduction of standards like ISO26262 [1] add further pressure on reliability assessment.

While in the past reliability has profited from a substantial – although in most cases unknown – safety margin, technologies and applications are pushed increasingly towards their limits. This development implies that established procedures for qualification following standards like AEC Q100 [2], AEC Q101 [3], or JEDEC JESD47 [4] have to be scrutinized regarding their suitability to fulfill the needs of reliability assessment and qualification. The paper is organized as follows:

Section 2 provides a definition of reliability as a common basis; Section 3 describes standard qualification procedures, whereas Section 4 lays out the basic idea of Robustness Validation. Section 5 discusses some basic aspects of mission profiles. Some salient features of lifetime assessment are discussed in Section 6. A few statistical aspects are touched upon in Section 7, and Section 8 summarizes the discussion and provides some outlook.

2. Reliability

The usual definition of reliability is given by (different but similar wordings can be found)

Reliability is the probability of an item to perform a required function under specified conditions for a specified time interval.

As Meeker and Escobar [5] have pointed out, it is more appropriate to state "…under *encountered* use conditions," because the specified conditions may not comprise the conditions the component is exposed to in the real application. Reliability is not an inherent property of the product but is related to the application requirements, i.e. the operational conditions and environmental factors under which a component works.

The definition expresses that reliability is not only fulfillment of a lifetime requirement, but fulfillment with a certain probability. Reliability assessment not only has physical and engineering aspects, but has statistical aspects that cannot be separated.

3. Standard qualification procedures

Common product qualification of semiconductor components is based on qualification standards such as AEC Q100 [2], AEC Q101

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[3], or JEDEC JESD47 [4]. These standards provide a set of stress tests (e.g. High Temperature Storage, Temperature Cycling) with pre-defined stress conditions and pre-defined sample size requirements. Tests are passed, if no fails are detected. It is a frequently found misconception that these tests (e.g. 1000 temperature cycles −55 °C to +150 °C) are reliability requirements. In fact, they are test methods. (No application will run at exactly −55 °C to +150 °C for exactly 1000 cycles over lifetime.) These tests originated by the intent to look at certain failure mechanisms. The question is: What do these tests tell us about the reliability of the product in a specific application?

Sample sizes required in the standards typically range from 25 to 77 pieces per lot for 3 lots. A sample size of 3 × 77 = 231 pieces with zero fails covers a failure probability of 1% at 90% confidence level. This is orders of magnitude from the low fail probabilities required in many applications. Section 7 deals with this topic in more detail.

Contrary to standard based product qualification, silicon wafer technology has followed a failure-mechanism-driven approach, looking at degradation and testing to fail, from the very beginning of silicon technology (see e.g. [6] for an overview).

4. Robustness Validation

4.1. The basic idea of Robustness Validation

Recognizing and acknowledging basic deficiencies of the standard based approach to product qualification, Robustness Validation of semiconductor components was introduced in 2007 [7] with a focus on automotive applications. However, it is obvious from what has been stated above that this approach is valid in a far more general way.

Fig. 1 illustrates the basic idea of Robustness Validation. The component has a certain specification that defines its operational area. An application, in which the component is used, is assumed to lie (should lie) within this specification area. For power devices this area is usually called the Safe Operating Area (SOA). The capability of the component, i.e. the area in which it operates reliably, is usually larger than the specified area. Outside this area of capability failures are to be expected. The robustness margin, i.e. the distance of the edge of the component's capability to the application, gives information on how much safety is available. This safety margin is needed due to, for instance, unknown variability of application conditions or process variability.

4.2. The Bathtub Curve and Robustness Validation

The component capability changes over time. In terms of the well-known bathtub curve, Robustness Validation focuses on the wearout region, as shown in Fig. 2. The stress tests typically applied in a qualification, e.g. electromigration, bias temperature tests, temperature storage and cycling, humidity tests and others, address this wearout region. Robustness Validation is limited in assessing the failure rates both in the early life (or infant mortality) region and in the steady state region.

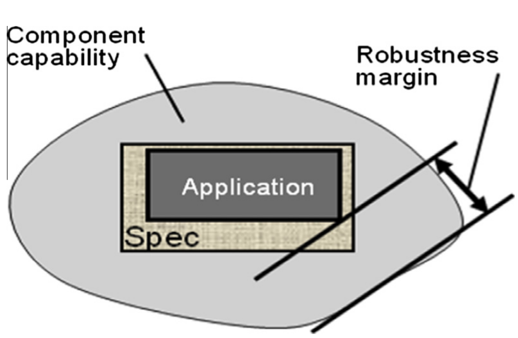

Fig. 1. Schematic illustration of the basic idea of Robustness Validation.

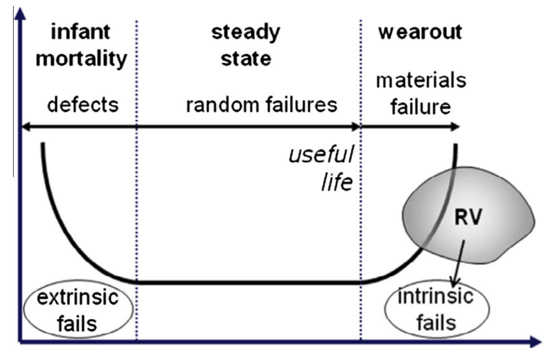

Fig. 2. The bathtub curve and the region addressed by Robustness Validation.

4.3. Reliability assessment flow

Contrary to a standard based qualification procedure with pre-defined stress tests a reliability assessment flow as it applies to Robustness Validation starts from the application requirements, i.e. the mission profile. This flow is shown in Fig. 3. The requirements given in the mission profile serve as the basis for a risk assessment. To perform this risk assessment the load conditions have to be related to the characteristics of the component. Detailed knowledge about the materials, the process and the design employed in the component is needed. The interaction of the component with the application loads leads to potential failure mechanisms, as is schematically depicted in Fig. 4. These failure mechanisms are the foundation of the reliability assessment and qualification plan. The qualification plan not only contains the stress conditions, and duration but also failure modes, the test vehicles, readout points and needs for analysis. The test results have to be assessed, i.e. the robustness of the component with respect to the requirements is derived. This flow relies heavily on knowledge and understanding of the materials, processes, and design and how they interact with the loads the component is exposed to.

4.4. Measures of Robustness

The Robustness Indicator Figure (RIF) is a means to quantify the Robustness. Essentially, it gives the ratio of the test time t_{test} to the time calculated from the mission profile t_{mp}, as shown in Eq. (1).

Fig. 3. Reliability assessment flow for Robustness Validation.