Knowledge Based Qualification of Semiconductor Devices

Introduction to the NXP Reliability Knowledge Framework

René Rongen, NXP Semiconductors, Nijmegen

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Outline

- Background
- NXP Reliability Knowledge Framework
  - Web based tool
  - Reliability Knowledge Matrix
  - Mission Profile Library
- Deployment
- Summary

Background - Trend

- New semiconductor technologies and application areas require in-depth knowledge on failure mechanisms and mission profiles
  - Sensors (T, RH, …)
  - Automotive high temperature applications (beyond Q100 grade 0)

- Industry standards and consortia are moving towards knowledge based qualification
  - JEDEC with JESD94
  - Automotive Electronic Council (AEC) with Q100/Q101
  - Zentralverband Elektrotechnik- und Elektronikindustrie (ZVEI) with Robustness Validation

Automotive Electronics Council
Component Technical Committee

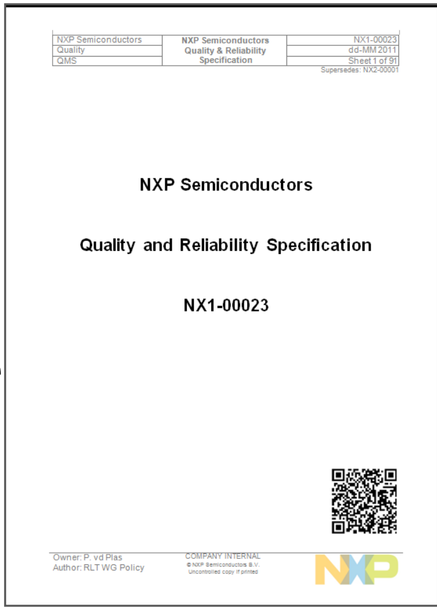
JEDEC Global Standards for the Microelectronics Industry

ZVEI: Die Elektroindustrie

Background - Trend - Response

- Knowledge Based Qualification needs to be described in more detail (systematic approach)
  - AEC Q100 Version H
  - ZVEI Robustness Validation Handbooks
  - **NXP Quality & Reliability Qualification** (Policy)

- Knowledge needs to be available and made accessible
  - JEP22
  - ZVEI Robustness Validation Knowledge Matrix
  - **NXP Reliability Knowledge Framework**



NXP Semiconductors	NXP Semiconductors	NX1-00023
Quality	Quality & Reliability	dd-MM 2011
QMS	Specification	Sheet 1 of 91

Supersedes: NX2-00001

NXP Semiconductors

Quality and Reliability Specification

NX1-00023

Owner: P. vd Plas
Author: RLT WG Policy

COMPANY INTERNAL

NXP Reliability Knowledge Framework
The principles

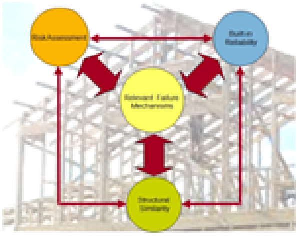
- Starting point
  - The “daily” user needs to be easily connected to the “frame work” of knowledge, data, tools and methods that is available in and outside the company
  - The scope of the framework is reliability qualification, monitoring and reliability oriented risk assessment (and will be extended to safe launch)

- Boundary conditions
  - All elements in the framework need to be up-to-date
  - Examples and training material should support company broad deployment and application

NXP Reliability Knowledge Framework

A web based tool

Reliability Knowledge Framework



This framework connects the user to NXP specific reliability knowledge, data, tools, and methods (including many examples). Easier than ever, using industry-wide wealth of reliability failure mechanisms collected in one unique overview you can build-in reliability, construct "customer tailored" qualification strategies, and make risk assessments in case of qualification failures or production incidents.

The framework thereby supports the Knowledge Based Qualification approach as used by NXP and defined in the NXP Quality and Reliability Specification.

The framework contains four basic elements:

1. The Reliability Knowledge Matrix (RKM), which is a database of all relevant failure mechanisms that are known within NXP. The RKM is based on the Robustness Validation Knowledge Matrix of the ZVEI, which is an add-on to JEP122. The RKM provides a concise summary of accessible and acknowledged information on failure mechanisms and failure causes, with further details related to these failure mechanisms.
2. Tools and methods to perform a Risk Assessment (RA). An RA shall be applied to determine the relevant failure mechanisms and to verify the technology capability of the applied building blocks (wafer fabrication process, package technology, IP) against the application and customer requirements. This part of the framework also contains the Mission Profile library.
3. Tools and methods for applying Built-in Reliability (BiR). By building reliability into the product design the required reliability test program can be reduced. This approach includes both the use of BiR tools and the application of reliability-related design rules.
4. Rules and tools for applying Structural Similarity, which enables the re-use of available generic data in reliability qualification or in the definition of reliability monitoring program.

NXP Reliability Knowledge Framework

High level structure

High Level Structure:

Reliability Knowledge Matrix		
Risk Assessment	Guidelines	• Risk Assessment in a Reliability Qualification Strategy
	Methods	• Design Assessment Reliability Testing (DART) • Risk Assessment for Incidents
	Tools	• Mission Profile Library • Lifetime Calculator • Distribution Plotting
Built-in Reliability		
Structural Similarity		

NXP Reliability Knowledge Framework

Reliability Knowledge Matrix, based on ZVEI RVKM:

http://www.zvei.org/Verband/Fachverbaende/ElectronicComponentsandSystems/Seiten/Robustness-Validation-Device-Level.aspx

Reliability Knowledge Matrix

Introduction

Objective

The Reliability Knowledge Matrix (RKM) intends to provide a concise summary of accessible and acknowledged information on failure mechanisms and failure causes with further details related to those failure mechanisms. It therewith provides a database to support risk assessments and definitions of qualification strategies. It is based on the ZVEI Robustness Validation Knowledge Matrix.

The RKM does not claim comprehensiveness and it does not release its user from his/her responsibility to consider the specifics of technology and product.

The RKM is regularly reviewed to keep abreast with the development of reliability knowledge of semiconductor technologies.

It delivers the basic input to the other elements in the Reliability Knowledge Framework (RKF):

- Risk Assessment
- Built-in Reliability
- Structural Similarity

Latest version of the Reliability Knowledge Matrix

NX5-00070 (RKM V3.0, released December 2011).

Reliability Knowledge Matrix

The Knowledge Matrix is made in excel and contains 6 worksheets:

- Worksheet 1: Introduction (scope and revision history)
- Worksheet 2: User guide (filtering in excel)
- Worksheet 3: Knowledge Matrix (actual database)
- Worksheet 4: Definitions (explaining the headers terms, subsystems, failure mechanism categories and failure mechanism coding)
- Worksheet 5: Abbreviations (list of used abbreviations, structured in categories)
- Worksheet 6: delta with ZVEI Robustness Validation Knowledge Matrix

NXP Reliability Knowledge Framework

Reliability Knowledge Matrix: 2 examples Cu-wire

					Reliability Knowledge Matrix	
					Version	3.0
					Date	2011-11
					Status	Final
Coding		**Classification**			**Description**	
New NXP Ref. No.	**Old NXP Ref. No.**	**Sub-System**	**Material/ Component**	**Failure Mechanism Category**	**Failure Mechanism**	**Failure Cause**
J2e5	new	package-chip-interface	molding compound, glue, Al bond pad, Au/ Cu - wire	corrosion	high temperature and/or moisture enhanced corrosion along the interface between Cu-ball and Cu-Al intermetallic	- contamination on pad surface (from wafer or assembly process) - impurities/contamination in raw material (molding compound, die attach glue, wire/bondpad material) - poor IMC coverage
J2d2e	37	package-chip-interface	Au/ Cu-wire, AlCu(Si), IMD, Si	crack	cratering: fracture through BEOL-stack & Si chip out	- mechanical stress exceeding the Si strength - enhanced by delamination along interface molding compound - die surface starting at corners - damage due to wrong wire bond settings - damage due to probing - extreme wire deformation during bonding/ molding

- Next to “classification” and “description”, more information is available on
  (not shown here):
  - Observation & Detection
  - Testing & Acceleration
  - References
  - Tools & Rules

NXP Reliability Knowledge Framework

Risk Assessment: Mission Profile Library

Mission Profile Library

Introduction

Objective

The NXP Mission Profile Library (MPL) is part of the Risk Assessment element in the RKF and documents the generic mission profiles (according to QRS) and other available application-specific mission profiles within NXP. A process will be developed for the release of application-specific mission profiles and their publication in the MPL.

In the MPL calculations can be carried out for the duration of the most commonly used product reliability tests to cover the expected field life of the application. Use is made of acceleration models as documented in the Reliability Knowledge Matrix with selected acceleration parameters.

The MPL is regularly reviewed and updated to ensure that the latest defined mission profiles are uploaded.

Differences between Mission Profile Library and Lifetime Calculator

Two tools are available in the RKF to calculate reliability test durations that are required to cover the application mission profile:

- The Lifetime Calculator computes the test duration per failure mechanism. The models that are applied are specific for a given failure mechanism and for a given wafer-fabrication process. Usage of the LC tool is recommended for the calculation of HTOL and LTOL test durations, provided that the models of the dominant failure mechanisms in the applied wafer-fabrication process have been implemented in the tool.
- The Mission Profile Library (MPL) computes the test duration per reliability test. This tool is the successor of the QRS Acceleration Model Calculator. The tool uses generic reliability models with fixed parameter values, independent of the applied technologies. The MPL tool is recommended for all cases where the LC tool is not applicable:
  - Reliability tests other than HTOL and LTOL;
  - HTOL and LTOL tests, if the relevant wafer-fabrication process and/or failure mechanisms have not been implemented in the LC tool.

  The following models are used in the MPL tool:
  - Arrhenius model for HTOL, LTOL, HTSL, and DRET;
  - Coffin-Manson model for TMCL, BL-TMCL, and TFAT;
  - Peck model for HAST, THB, H3TRB, UHST, and PPOT/AC.

Latest version of the Mission Profile Library

Latest version of the NXP MPL (V1.0, released December 2011).

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NXP Reliability Knowledge Framework
Risk Assessment: Mission Profile Library

- A Mission Profile (MP) is a collection of relevant environmental and functional loads that a product will be exposed to during its full life cycle.

T?

I?

operational time?

ΔT?

V?

life time?

RH?

f?

NXP Reliability Knowledge Framework

Risk Assessment: Mission Profile Library

- The principle of acceleration

Reliability test at stress conditions → Failure mechanism at application condition

$$\text{Acceleration factor} = \frac{\text{Time to failure in application}}{\text{Time to failure in stress}}$$

NXP Reliability Knowledge Framework

Risk Assessment: Mission Profile Library

1. Input

Field to be filled in

Field Lifetime	=	10	Years
Power On Hours	=	1.5	hours/day
cycles/day	=	1	cycles/day
$T_{a,max-eff}$	=	90	°C
ΔT_{self}	=	20	°C
$T_{j,max-eff}$	=	110	°C
T_a	=	10-70	°C
$T_{e,min-eff}$	=	10	°C
$T_{trop,day}$	=	30	°C
$T_{trop,night}$	=	15	°C
Relative Humidity	=	95	%

2. Description Mission Profile

Simplified Mission Profile

Field Lifetime	Power-On-Hours (POH)		Relevant Temperatures °C		Stimuli
Operation					
years	hours/day	hours/field life	$T_{j,max-eff}$	T_a	(V, I, f, loading)
10	1.5	5475	110	10-70	Application Specific
Thermo Mechanical Loading					
Field Lifetime	Power Cycles		Relevant Temperatures °C		Effective Temperature Cycle °C
years	cycles/day	cycles/field life	$T_{j,max-eff}$	$T_{e,min-eff}$	ΔT_{eff}
10	1	3650	110	10	100
Humid Environment					
Field Lifetime	Time Off-Standby		Relevant Temperatures °C		Relative Humidity
years	hours/day	hours/field life	$T_{trop,day}$	$T_{trop,night}$	%
10	22.5	82125.0	30	15	95
Hot Environment					
Field Lifetime	POH + Time Off-Standby		Relevant Temperatures °C		
years	hours/day	hours/field life	$T_{j,max-eff}$	$T_{trop,day}$	
10	1.5 + 22.5	87600	110	30	

3. Output

Calculated required test times

Tests	Test Condition		Based on Simple Mission Profile		Based on Detailed Misson Profile		Values used kB = 8.62E-05 eV/K		
HTOL	150 °C		738	h	228	h	Ea (eV) =	0.7	
LTOL	25 °C						Ea (eV) =	-0.15	1
	3 V (during test)				1024	h	$AF_{techn\ dep}$ = / V_{type} =	40	2.8
DRET	150 °C		1104	h			Ea (eV) =	0.6	
HTSL	150 °C		314	h	62	h	Ea (eV) =	1	
TMCL / TC	-65 °C	150 °C	79	c	79	c	n =	5	
IOL / TFAT	20 °C	95 °C	260	c			n =	2	
HAST / UHST	130 °C	85 %	90	h			n = / Ea (eV) =	2.7	0.7
PPOT / AC	121 °C	100 °C	92	h			n = / Ea (eV) =	2.7	0.7
THB / H3TRB	85 °C	85 °C	1128	h			n = / Ea (eV) =	2.7	0.7
BL TMCL	-40 °C	125 °C	798	c			n =	2.1	0

Acceleration model

Deployment

- In 2011 the Reliability Knowledge Framework has been deployed via a company wide training program
- Every product reliability qualification strategy consists of a section concerning the application based reliability risk assessment
- Guidelines are given on how to use the reliability knowledge framework in this risk assessment
- All the reliability qualification strategies are subjected to a review process
- During the review the use of the framework is checked by and discussed with peers
- Since 2012 the correct use of the framework is monitored via a performance indicator
- The review process is also used to collect user input for future improvements of the framework

Summary

- Knowledge Based Qualification of Semiconductor Devices can only be successfully applied if knowledge is available and accessible
- To that purpose NXP developed a Reliability Knowledge Framework that is available since end 2010
- It consists of knowledge, data, tools and methods offered to the "daily user" via a website that also includes explanation, examples, references and training material
- The NXP Reliability Knowledge Framework is successfully being applied in e.g. the Au to Cu-wire conversion program