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Failure Mechanisms and Models for Semiconductor Devices

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FAILURE MECHANISMS AND MODELS FOR SEMICONDUCTOR DEVICES

Foreword

This publication provides guidance in the selection of reliability modeling parameters, namely functional form, apparent thermal activation energy values, and sensitivity to stresses such as power supply voltage, substrate current, current density, gate voltage, relative humidity, temperature cycling range, mobile ion concentration, etc.

The failure mechanisms described in the several sections of this publication constitute commonly accepted industrial models, validated by a team of reliability experts (SEMATECH/ISMI Reliability Council) and buttressed by citations to the most cogent published literature.

Revisions have been made to reflect technology changes, especially as Cu now supplements Al and low-dielectric-constant insulators are complementing traditional silica.

Introduction

Accelerated tests are typically used to find and identify potential failure mechanisms in semiconductor devices and to estimate the rate of their occurrence in electronic systems. The historical approach to investigating the relationship between a maximum stress failure rate and a system failure rate is to choose a single representative "equivalent" apparent thermal activation energy for a given product or product group. A single, best-estimate apparent activation energy value facilitates accurate estimation of the acceleration factor for the device failure rate estimation in the system application.

A word about formats within this document: parentheses **( )** enclose equation numbers; square brackets **[ ]** enclose citation numbers. All equation, citation, and figure numbers include the subclause number so that individual clauses can be modified without disturbing other clauses, except for page numbers. Thus, **(5.3.2)** is the 2nd equation in 5.3 and **[5.11.5]** is the 5th citation in 5.11. The citations can be found in Annex A.

FAILURE MECHANISMS AND MODELS FOR SEMICONDUCTOR DEVICES

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1 Scope

This publication provides a list of failure mechanisms and their associated activation energies or acceleration factors that may be used in making system failure rate estimations when the only available data is based on tests performed at accelerated stress test conditions. The method to be used is the Sum-of-the-Failure-Rates method.

The models apply primarily to the following:

a) Aluminum (doped with small amounts of Cu and/or Si) and copper alloy metallization

b) Refractory metal barrier metals with thin anti-reflection coatings

c) Doped silica or silicon nitride interlayer dielectrics, including low-dielectric-constant materials

d) Poly silicon or “salicide” gates (metal-rich silicides such as W, Ni & Co to decrease resistivity)

e) Thin SiO_2 gate dielectric

f) Silicon with p-n junction isolation

g) Tin Whisker Growth Kinetics

h) Printed Circuit Board Ionic Mobility

2 Terms and definitions

For the purpose of this publication, the following terms and definitions apply.

acceleration factor (*A*, AF): For a given failure mechanism, the ratio of the time it takes for a certain fraction of the population to fail, following application of one stress or use condition, to the corresponding time at a more severe stress or use condition.

NOTE 1 Times are generally derived from modeled time-to-failure distributions (lognormal, Weibull, exponential, etc.).

NOTE 2 Acceleration factors can be calculated for temperature, electrical, mechanical, environmental, or other stresses that can affect the reliability of a device.

NOTE 3 Acceleration factors are a function of one or more of the basic stresses that can cause one or more failure mechanisms. For example, a plot of the natural log of the time-to-failure for a cumulative constant percentage failed (e.g., 50%) at multiple stress temperatures as a function of $1/kT$, the reciprocal of the product of Boltzmann’s constant in electronvolts per kelvin and the absolute temperature in kelvins, is linear if one and only one failure mechanism is involved. The best-fit linear slope is equal to the apparent activation energy in electronvolts.

NOTE 4 The abbreviation AF is often used in place of the symbol *A*.

acceleration factor, stress (A_f): The acceleration factor due to the presence of some stress (e.g., current density, electric field, humidity, temperature cycling).