

JEDEC PUBLICATION

A Procedure for Performing SWEAT

JEP119A

(Revision of JEP119)

AUGUST 2003 (Reaffirmed: October 2012)

JEDEC SOLID STATE TECHNOLOGY ASSOCIATION



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A PROCEDURE FOR PERFORMING SWEAT

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A PROCEDURE FOR PERFORMING SWEAT

(From JEDEC Board Ballot JCB-03-07, formulated under the cognizance of the JC-14.2 Subcommittee on Wafer-Level Reliability.)

1 Scope

This document describes an algorithm for performing the Standard Wafer Level Electromigration Accelerated Test (SWEAT) method with computer controlled instrumentation. The algorithm requires a separate iterative technique (not provided) to calculate the force current for a given target time to failure.

This document does not specify what test structure to use with this procedure. However, users of this algorithm report its effectiveness on both straight-lines and via-terminated test structures. Some test-structures design features are provided in JESD87 and in ASTM 1259M - 96.

2 Introduction

The SWEAT method is an accelerated electromigration test performed on microelectronic metallizations. This highly accelerated test was developed as a method for obtaining quickly a measure of metallization reliability and for providing process control data to the semiconductor manufacturer.

This document presents an algorithm for performing the SWEAT method with computer controlled instrumentation. The algorithm is derived from published and unpublished literature. It provides little innovation beyond what is currently documented. The intent is to provide a complete description of a basic, functional, SWEAT algorithm that will facilitate software development and the use of highly accelerated stress testing.

The SWEAT algorithm uses a feedback control loop to adjust the stress current applied to the metallization under test. Using Black's equation, the stress current is adjusted such that the temperature and current density of the structure maintain the estimated time to failure within an error band of the selected target value.

3 Applicable documents

Root, B. and Turner, T., *Wafer Level Electromigration Tests for Production Monitoring*, IEEE/International Reliability Physics Symposium, 1985, pp. 100-107.

Von Hagen, J., Antonin, G., Fazekas, J., Head, L., and Schafft, H., *New SWEAT Method for Fast, Accurate and Stable Electromigration Testing on Wafer Level*, IEEE/Integrated Reliability Workshop, Final Report, 2000, pp. 85-89.

Zitzelsberger, A., Bauer, R., Von Hagen, J., Lepper, M., and Pietsch, A., *Electromigration Testing on Via Line Structures with Fast Wafer Level Tests in Comparison to Standard Package Level Tests*, IEEE/International Interconnect Technology Conference, Final Report, 2000, pp. 180-182.

3 Applicable documents (cont'd)

JEDEC Standard JESD33A, *Standard Method for Measuring and Using the Temperature Coefficient of Resistance to Determine the Temperature of a Metallization Line.*

JEDEC Standard JESD37, *Standard for Log normal Analysis of Uncensored Data, and of Singly Right-Censored Data Utilizing the Persson and Rootzen Method.*

JEDEC Standard JESD61, *Isothermal Electromigration Test Procedure.*

EIA/JEDEC Standard EIA/JESD63, *Standard Method for Calculating the Electromigration Model Parameters for Current Density and Temperature.*

JEDEC Standard JESD87, *Standard Test Structures for Reliability Assessment of AlCu Metallization with Barrier Materials.*

ASTM 1259M-96, *Standard Guide for Design of Flat, Straight-Line Test Structures for Detecting Metallization Open-Circuit or Resistance-Increase Failure Due to Electromigration.*

4 Terms and definitions

4.1 estimated time to failure (t_{FE}) {s}

The time it takes for the combined stress of temperature and current density to result in a prescribed increase in resistance of the test structure (definition of failure) as determined from Black's equation¹.

$$t_{FE} = A \cdot J^{-n} \cdot e^{E_a/kT} \quad (1)$$

where: A is an empirically determined constant, provided by the user

J is the current density (A/cm²).

n is the current density factor, provided by the user
(value of 2 is often used, but larger or smaller values have been reported.)

E_a is the activation energy of the metallization, provided by the user (eV).

k is Boltzmann's constant (8.62E-5 eV/K), and.

T is the mean temperature of the test structure (K).

¹ BLACK, S. R., *Electromigration of Al-Au Alloy Films*, Proc: International Reliability Physics Symposium, 1978, pp. 233-240.

4 Terms and definitions (cont'd)

4.2 failure resistance criterion (R_{FC}) $\{\Omega\}$

The resistance at or above which the test structure is considered to have failed.

NOTE It is equal to the product of the resistance of the test structure at the end of the initial settling period and a preselected fractional increase in resistance.

4.3 resistance at chuck temperature (R_{CT}) $\{\Omega\}$

The resistance of the test structure at the wafer chuck temperature, T_{CT} , before the test structure is subjected to joule heating in accordance with the SWEAT algorithm.

4.4 chuck temperature (T_{CT}) $\{^{\circ}\text{C}\}$

The metallization temperature at the time R_{CT} is measured; this is the temperature of the structure before joule heating.

4.5 temperature coefficient of resistance [$\text{TCR}(T_{\text{ref}})$] $\{^{\circ}\text{C}^{-1}\}$

The fractional change in resistance of the test structure per unit change in temperature at a specified temperature, T_{ref} , as described in the following equation:

$$\text{TCR}(T_{\text{ref}}) = \frac{1}{R(T_{\text{ref}})} \cdot \frac{\Delta R}{\Delta T} \quad (2)$$

NOTE For aluminum alloy metallizations, the change in resistance of the test structure with temperature is approximately constant from room temperature to about 420 $^{\circ}\text{C}$. For copper alloy metallizations, a change in $\Delta R/\Delta T$ becomes evident at temperatures as low as 230 $^{\circ}\text{C}$. Hence, if $\text{TCR}(T_{\text{ref}})$ is to be used to calculate the temperature of copper test structure at higher temperatures, a correction factor, F_{corr} will be required (see 6.2.2 and 7.6).

4.6 thermal resistance (R_{th}) $\{^{\circ}\text{C}/\text{W}\}$

The change in mean temperature of the test structure divided by the change in the power dissipation ($I_{\text{frc}}^2 \times R(T)$) that causes the temperature increase in the structure.

$$R_{\text{th}} = \Delta T / \Delta P \quad (3)$$

NOTE R_{th} is dependent on the geometry of the test structure and on the thermal conductance to the ambient, which is temperature dependent (see 7.7). In a plot of T versus P , the thermal resistance is the slope of the curve. Because the thermal conductance of the materials in the path of the heat flow from the test structure is temperature dependent, the slope will gradually change with increasing power dissipation. However, the thermal resistance can be regarded as a constant over the limited range of temperatures experienced by the test structure after the stress temperature has been attained. It is assumed that the change in resistance of the test structure due to electromigration does not, to the first order, affect its thermal resistance.

4 Terms and definitions (cont'd)

4.7 target time to failure (t_{FT}) {s}

The desired time it should take for the resistance of the test structure to first equal or exceed the failure resistance criterion, R_{FC} , while the structure is under stress from the SWEAT algorithm.

4.8 starting current density (J_S) {A/cm²}

The current density in the narrowest region of the test structure at the initial application of the forcing current, I_{fc} .

NOTE The current density is calculated using area, a .

4.9 forced current (I_{fc}) {A}

The current that is forced through the test structure. See 6.2.3, 6.2.5, and 6.2.7.

4.10 area (a) {cm²}

The cross-sectional area of the narrowest region of the test structure.

4.11 error band (B_E) {s}

The band centered around the target time to failure, t_{FT} , within which the SWEAT algorithm will not permit the feedback control loop to adjust the forcing current, and whose boundaries ($t_{FT} + B_E$ and $t_{FT} - B_E$) constitute the limits for the estimated time to failure, t_{FE} , where B_E is half the width of the error band

$$t_{FT} - B_E < t_{FE} < t_{FT} + B_E \quad (4)$$

4.12 time to failure (t_F) {s}

The time it takes for the resistance of the test structure to first equal or exceed the failure resistance criterion, R_{FC} , while the structure is under stress from the SWEAT algorithm.

4.13 resistance at failure (R_F) { Ω }

The value of the last recorded resistance of the test structure during the control cycle before the failure criterion, R_{FC} , is satisfied.

4.14 current density at failure (J_F) {A/cm²}

The value of the last recorded current density in the narrowest region of the test structure during the control cycle before the failure criterion, R_{FC} , is satisfied.

NOTE The current density is calculated using area, a .