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INTERNATIONAL STANDARD

NORME INTERNATIONALE

Semiconductor devices – Constant current electromigration test

Dispositifs à semiconducteurs – Essai d'électromigration en courant constant

IEC 62415:2010

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

SEMICONDUCTOR DEVICES –
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FOREWORD

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International Standard IEC 62415 has been prepared by IEC technical committee 47: Semiconductor devices.

The text of this standard is based on the following documents:

FDIS	Report on voting
47/2044/FDIS	47/2054/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

SEMICONDUCTOR DEVICES – CONSTANT CURRENT ELECTROMIGRATION TEST

1 Scope

This standard describes a method for conventional constant current electromigration testing of metal lines, via string and contacts.

2 Symbols, terms and definitions

For the purposes of this document, the following symbols, terms and definitions apply:

2.1 Symbols

2.1.1
J_{via_use}
the maximum current density permitted to flow in a via of a real product

2.1.2
J_{line_use}
the maximum current density permitted to flow in a line of a real product

2.1.3
J_{via_test}
the current density in a via of a test structure during electromigration test

2.1.4
J_{line_test}
the current density in a line of a test structure during electromigration test

2.1.5
t(x %)
time to failure of *x* % of the population

NOTE The method for calculation of *t* (50 %) is described in Clause 8.

2.2 Terms and definitions

2.2.1
TEG
test element group. This is the test structure used for the test

2.2.2
Blech length
the line length below which electromigration time to failure increases sharply [1][1]

NOTE The drift of metal atoms causes stress build-up in the metal lines, which caused a back flow of atoms.

For short lines the stress gradient is higher than for long lines with the same current density. The forward flow increases more rapidly with current density than the backflow, and consequently the Blech length is inversely proportional to the current density. The Blech length can be determined by using a chain with different line lengths between the vias.

1 Figures in square brackets refer to the Bibliography.

3 Background

The background of electromigration testing as described in this procedure is based on the assumption that the entire electromigration failure time distribution stays intact when accelerated. Acceleration can be described by an activation energy and a current acceleration factor, as originally proposed by Black [2].

4 Sample size

15 samples or more are recommended for each test (each test structure, temperature and current density). In some cases, to get a better statistical confidence of the results or to analyze a bimodal distribution, a higher number of samples might be necessary.

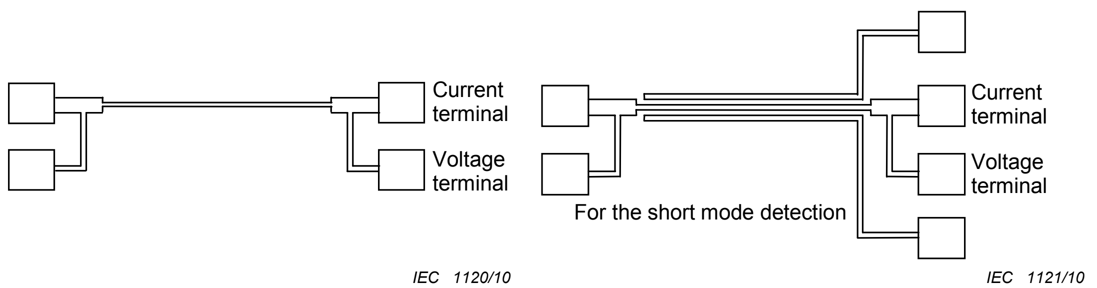
5 Test structures

5.1 Lines

Electromigration characterization shall be carried out on fully back-end processed samples. The metal line test structure in a 4-terminal (Kelvin) configuration shall be used (see Figure 1a).The line length is recommended to be at least 800 μm. The use of monitors for opens, inter-layer shorts and optional intra-layer shorts is recommended (see Figure 1b).The line length is determined by the constraints that short lines are not sensitive to failure and exhibit the Blech effect [1], and too long lines require high voltages. For line lengths <200 μm the Blech effect shall be verified.

The line width shall be process-dependent. Narrow lines carry higher current densities and are more susceptible to electromigration failure. On the other hand, lines with width smaller than the grain size may have longer lifetime than wider lines due to the bamboo effect [3]. Therefore, lines with the minimum design rule width or the line width that gives the shortest life time (e.g. wide lines with width greater than the grain size, that are more representative of the current carrying lines in the circuit) shall be used in the test. Other line widths may be added if necessary.

Metal lines of each layer, both over a flat surface as well as over topography (only for processes without planarized back-end), should be used.



a) TEG of four terminals b) TEG with short mode detection line

Figure 1 – TEG of electromigration evaluation for metal line

5.2 Via chains

This is a chain of vias between metal layers connected in series. The via chain test structure shall contain at least 10 vias (see Figure 2).

As an option, test structures may be used where the contacts between metal layers are formed by a number of vias in parallel. The number of vias per contact may be determined by the following requirement:

$$\frac{J_{via\_test}}{J_{line\_test}} = \frac{J_{via-use}}{J_{line\_use}} \tag{1}$$

Via size shall be the minimum design dimensions. Metal line length between vias shall exceed the Blech length, to avoid stress induced atomic back diffusion counteracting electromigration. For line lengths <200 µm the Blech effect shall be verified.

Via current density is defined as the current divided by the via area (ignoring current crowding).

Figure 2 – TEG of electromigration evaluation for vias

5.3 Contact chains

This is a chain of contacts to n+ in substrate or p-well, or p+ in n-well. The number of contacts shall be kept low as the voltage required to force the stress current is limited by the junction breakdown voltage. Contact size shall be the minimum design dimension. Metal length between contacts shall exceed the Blech length. For line lengths <200 µm the Blech effect shall be verified.

Contact current density is defined as the current divided by the contact area (ignoring current crowding).

6 Test conditions

Current density values are determined by the constraints that too low currents cause long test times, and too high currents may cause non-uniform heating and irrelevant failures. Practical values are in the order of 10^5 A/cm^2 – 10^6 A/cm^2 for both Al and Cu lines. For contacts and vias, 10 times the design limit is typically used.

It shall be verified if Joule heating is significant. This verification is done by determining the temperature coefficient of resistance of the metal line, and comparing the resistance at the test condition with the resistance at low current density. When Joule heating is significant the line temperature shall be corrected for Joule heating [4] and data shall be available to demonstrate that the failure mechanism has not changed.

Test ambient temperature is typically 150 °C – 250 °C (250 °C – 350 °C for Cu). Higher temperatures are allowed if no change in mechanism can be demonstrated.

The typical test conditions shown above guarantee usually sufficient degradation in a reasonable time (days or weeks).

7 Failure criteria

Open failure: typically 10 % – 30 % resistance change.

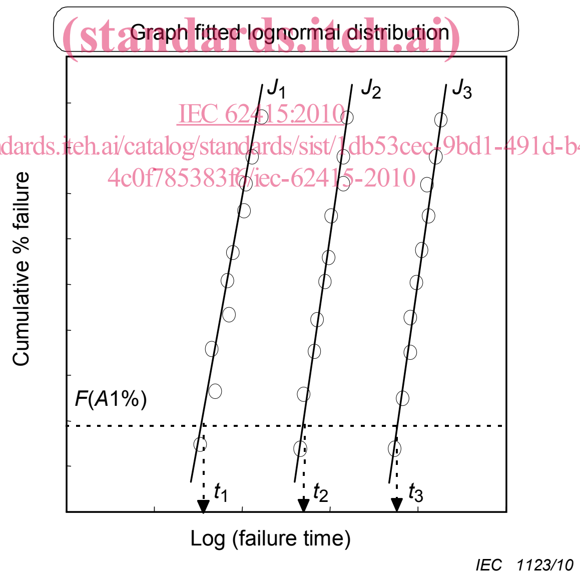
Short failure: contact detection in extrusion monitors.

Contact spiking: a substrate leakage current increase of two decades.

8 Data analysis

The time to failure is estimated by fitting a lognormal distribution through the data points (see Figure 3). For plotting the use of the failed fraction according to the mean rank method is recommended: $f = n/(N + 1)$, in which f is the failed fraction, n is the number of failed test structures and N the total sample size. The use of other methods , e.g. median rank ($f = (n – 0,3)/(N + 0,4)$), is allowed but shall be reported. Fitting to be done with the least squares or maximum likelihood methods. Calculate the each failure time $t(F\%)$.

The confidence interval is determined using the t-distribution. The confidence level used shall be reported



Key

J_1,J_2,J_3(A/cm^2) :
stress current density to line or via

$J_1 > J_2 > J_3$ (A/cm^2)

t_1,t_2,t_3(h): failure time when the cumulative failure reaches A1 percent.

Figure 3 – Graph fitted lognormal distribution

Extrapolation to other conditions is done using Black's equation with no line width term:

$$t(x\%) = A \cdot j^{-n} \cdot \exp(Ea/(k \cdot T)) \quad (2)$$

where

A is a process-dependent factor,

j is the current density,

n is the current exponent,

Ea is the activation energy,

k is the Boltzmann constant, and

T is the absolute temperature.

It is assumed that this formula holds for all fail percentages, in other words that the spread of the distribution is not affected by the acceleration.

For the determination of the activation energy *Ea*, three temperatures, and for the determination of the current density exponent *n*, three current densities should be used.

The power exponent "*n*" is determined by plotting for a fixed temperature the logarithm of *t*(*A1* %) versus current density. The slope of this plot gives *n* (see Figure 4).

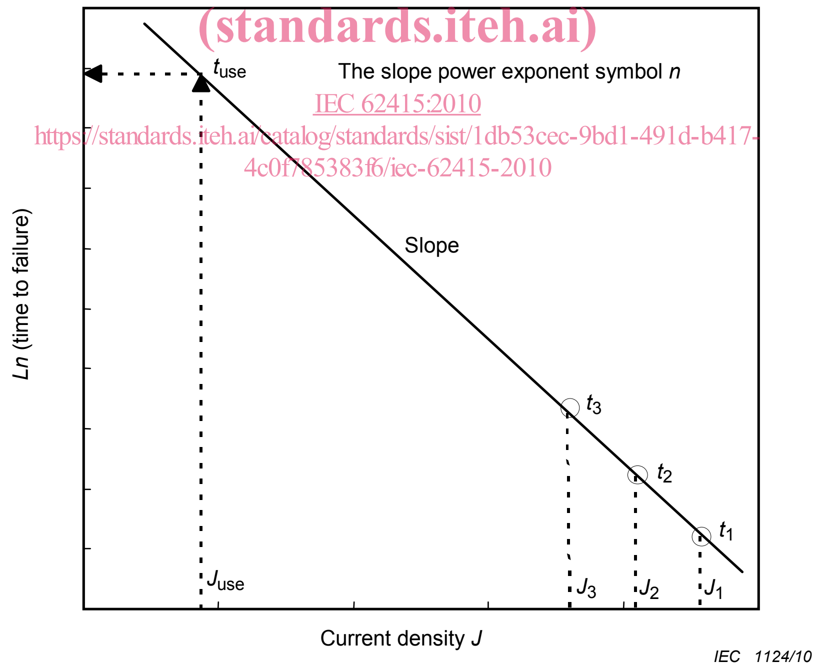


Figure 4 – Estimate procedure of current density exponent

The activation energy is determined by plotting for a fixed current density the logarithm of *t*(*A1* %) versus 1/*T*. The slope of this plot gives *Ea* (see Figure 5). Using above acceleration factors, estimate lifetime *t*(*F*%) in the use condition (a certain temperature and current density).

NOTE For Log normal distribution the correct time to be determined is the time at 50 % failure. It has the largest confidence. So, when the current density power exponent or temperature acceleration factor is calculated, it is preferable to calculate using the failure rate which is near to 50 %.