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Environmental acceptance requirements for tin whisker susceptibility of tin and tin alloy surface finishes on semiconductor devices

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The UK participation in its preparation was entrusted to Technical Committee EPL/47, Semiconductors.

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NORME INTERNATIONALE

colour inside

Environmental acceptance requirements for tin whisker susceptibility of tin and tin alloy surface finishes on semiconductor devices

Exigences de réception environnementale pour la susceptibilité des finis de surface en étain et alliage d'étain à la trichite d'étain sur les dispositifs à semiconducteurs

INTERNATIONAL ELECTROTECHNICAL COMMISSION

COMMISSION ELECTROTECHNIQUE INTERNATIONALE

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ENVIRONMENTAL ACCEPTANCE REQUIREMENTS FOR TIN WHISKER SUSCEPTIBILITY OF TIN AND TIN ALLOY SURFACE FINISHES ON SEMICONDUCTOR DEVICES

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International Standard IEC 62483 has been prepared by IEC technical committee 47: Semiconductor devices.

This first edition is based on JEDEC documents JESD201A and JESD22-A121A and replaces IEC/PAS 62483, published in 2006. This first edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) The content of IEC/PAS 62483 was added to the content of JESD201A as Annex A.

b) A methodology was introduced for environmental acceptance testing of tin-based surface finishes and mitigation practices for tin whiskers.

c) A Clause 6 was introduced detailing the reporting requirements of test results.

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

FDIS	Report on voting
47/2171/FDIS	47/2180/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- withdrawn,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.

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INTRODUCTION

Many companies in the electronics industry have adopted tin-based surface finishes as one of the methods to comply with various legislative lead-free (Pb-free) initiatives, e.g., the European Union’s RoHS directive. However, tin (Sn) and tin alloy surface finishes may be prone to tin whisker formation with associated possible reliability degradation. Appropriate mitigation practices may be incorporated to reduce tin whisker propensity to an acceptable level.

Test conditions in accordance with Annex A and qualification limits presented in this International Standard are based on known Sn whisker data from around the world. These test conditions have not been correlated with longer environmental exposures of components in service. Thus, there is at present no way quantitatively to predict whisker lengths over long time periods based on the lengths measured in the short-term tests described in this document. At the time of writing, the fundamental mechanisms of tin whisker growth are not fully understood and acceleration factors have not been established. Therefore, the testing described in this document does not guarantee that whiskers will or will not grow under field life conditions.

ENVIRONMENTAL ACCEPTANCE REQUIREMENTS FOR TIN WHISKER SUSCEPTIBILITY OF TIN AND TIN ALLOY SURFACE FINISHES ON SEMICONDUCTOR DEVICES

1 Scope

This International Standard describes the methodology applicable for environmental acceptance testing of tin-based surface finishes and mitigation practices for tin whiskers on semiconductor devices. This methodology may not be sufficient for applications with special requirements, (i.e. military, aerospace, etc.). Additional requirements may be specified in the appropriate requirements (procurement) documentation.

This International Standard does not apply to semiconductor devices with bottom-only terminations where the full plated surface is wetted during assembly (for example: quad-flat no-leads and ball grid array components, flip chip bump terminations). Adherence to this standard includes meeting the reporting requirements described in Clause 6.

2 Terms and definitions

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

2.1
base metal
metal alloy residing beneath all surface finish(es) and/or underplate

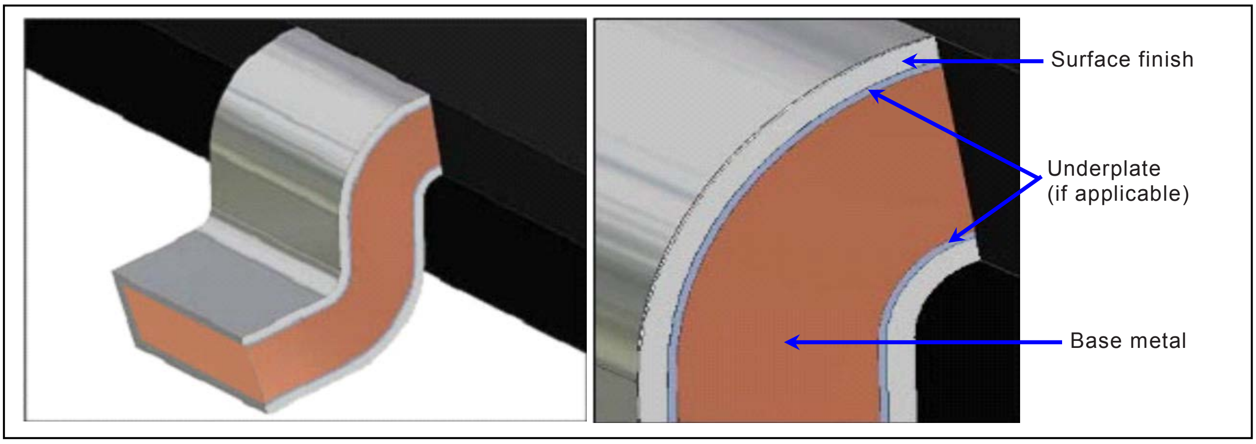

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Figure 1 – Cross-sectional view of component surface finishes

2.2
tin and tin alloy surface finish
tin-based outer surface finish for external component terminations and other exposed metal

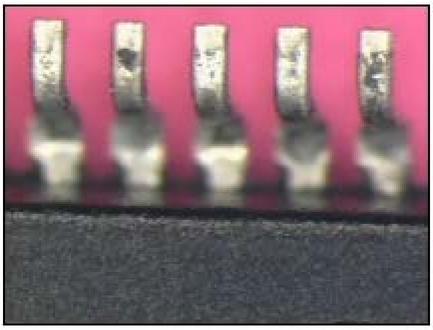
2.3
tin whisker mitigation practice
process(es) performed during the manufacture of a component to reduce the propensity for tin whisker growth by minimizing the surface finish internal compressive stress

2.4
manufacturing process change acceptance
acceptance testing of a change to a surface finish manufacturing process already accepted by technology acceptance tests (qv)

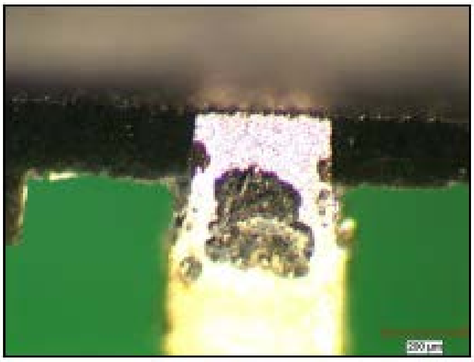
2.5
similarity acceptance
acceptance of a change to a surface finish manufacturing process based upon similarity and data available from previous tin whisker technology and manufacturing process change acceptance tests

2.6
surface corrosion
localized change to a silver-coloured tin surface finish appearing in an optical microscope as non-reflective dark spots ranging in size from about 25 μm on the longest dimension to the entire termination

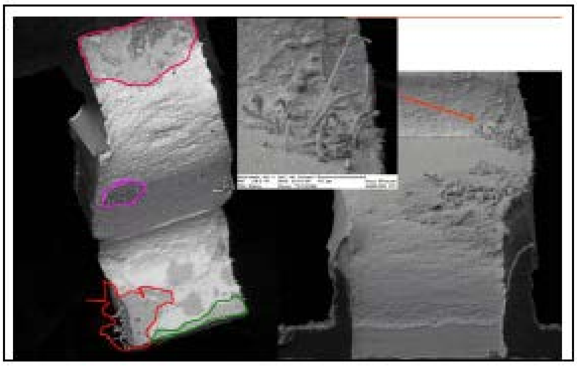
Note 1 to entry: While tin oxide is ubiquitous on tin surface finishes, surface corrosion creates a locally thick layer of tin oxide that may span from the substrate to the surface of the deposit at the black spot. Typical photos of termination corrosion are shown in Figure 2 (a) to d)).



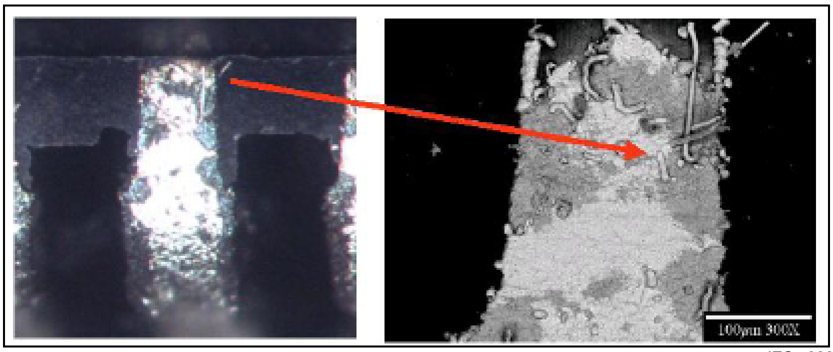
a) Matte Sn on Cu with Ni plate (optical)



b) Matte Sn on Cu (optical)



c) Matte Sn on Cu (SEM)



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d) Matte Sn on Cu (optical/SEM)

Figure 2 – Typical photographs of termination corrosion

2.7
surface finish technology acceptance
acceptance testing of surface finish material set and manufacturing processes that includes a defined set of base metals, underplating metals, surface finish alloy, surface finish bath chemistry and process flow steps

2.8
underplate
underlay
plated layers between the base metal and the outer surface finish

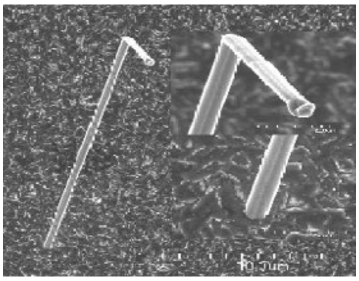
2.9
whisker
spontaneous columnar or cylindrical filament, usually of monocrystalline metal, emanating from the surface of a finish

EXAMPLE See Figure 3 for example pictures of tin whiskers.

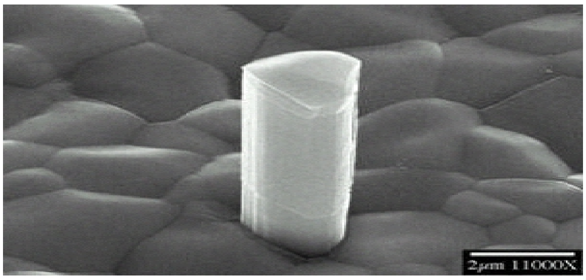
Note 1 to entry: For the purposes of this document, whiskers have the following characteristics:

- they have an aspect ratio (length/width) greater than 2;
- they can be kinked, bent, or twisted;
- they usually have a uniform cross-sectional shape;
- they typically consist of a single columnar filament that rarely branches;
- they may have striations along the length of the column and/or rings around the circumference of the column;
- they have a length of 10 μm or more (features less than 10 μm may be deemed important for research but are not considered significant for this test method).

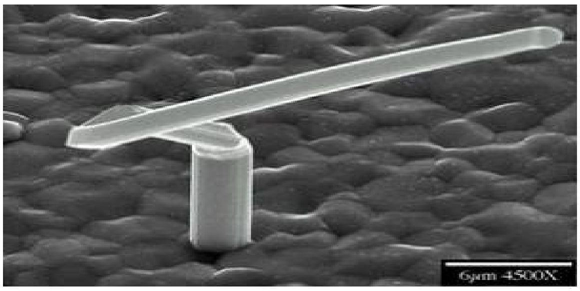
Note 2 to entry: Whiskers are not to be confused with dendrites, fern-like growths on the surface of a material which can be formed as a result of electromigration of an ionic species or produced during solidification. (See Figure 4 for a picture of a typical solidification dendrite.)



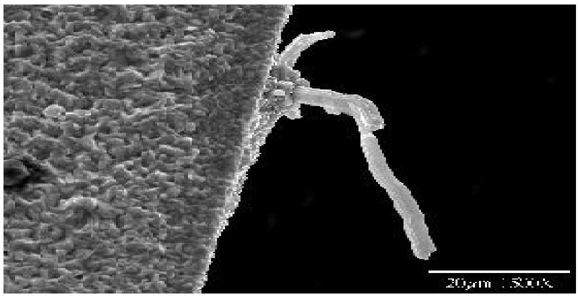
a) Tin whisker filaments



b) Whisker with a consistent cross section

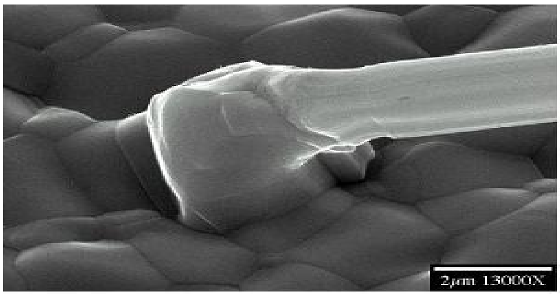


c) Kinked whisker

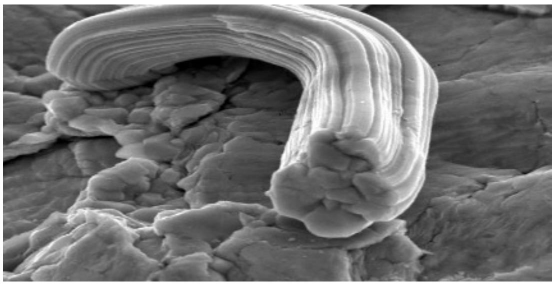


d) Kinked whiskers growing from a nodule

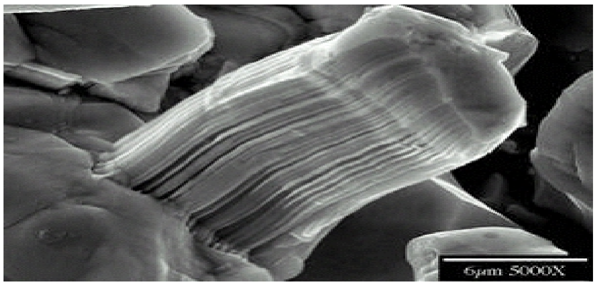
e) Branched tin whiskers on bright tin (rare)



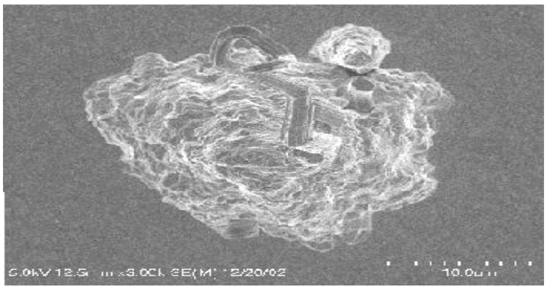
f) Whisker initiating from a hillock



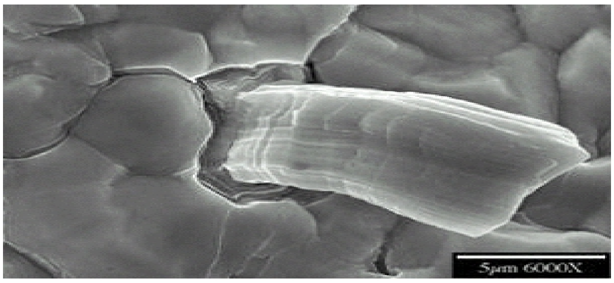
g) Tin whisker filament with striations



h) Tin whisker filament with striations



i) Kinked whisker on odd-shaped eruptions



j) Tin whisker with rings

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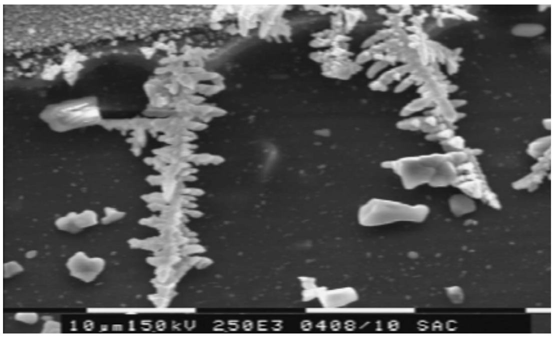
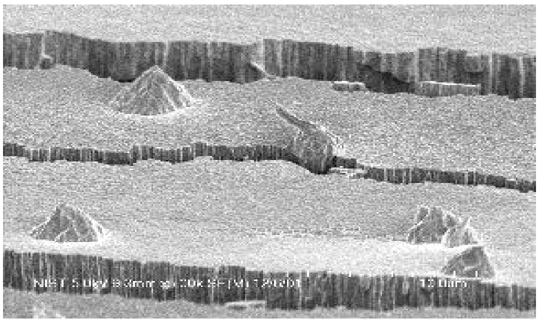
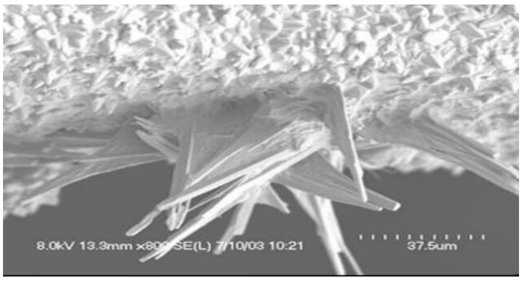
Figure 3 – Examples of tin whiskers



a) Dendrites are fern-like growths formed for example as a result of solidification. They are not whiskers



b) Hillocks may be precursors to whiskers in some cases, but are not considered whiskers for the purposes of this test method



c) "Flower" created on a tin plating exposed to the test condition of high-temperature humidity storage and is most likely a result of a combination of surface contamination and condensation

d) Dendrites formed on a tin surface during plating. These are not tin whiskers

IEC 2385/13

Figure 4 – Non-whisker surface formations

2.10
whisker length
straight line distance from the point of emergence of the whisker to the most distant point on the whisker

Note 1 to entry: The whisker length is the radius of a sphere containing the whisker with its centre located at the point of emergence, see Figure 5.

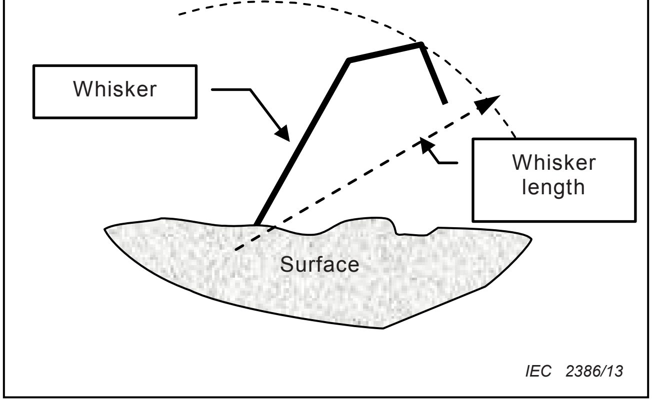


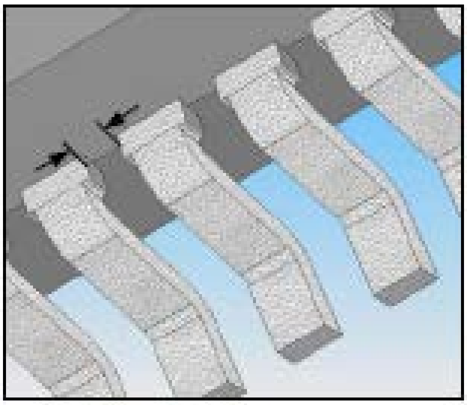
Figure 5 – Whisker length measurement

2.11
whisker density
number of whiskers per unit area on a single lead or coupon area

2.12
whisker growth
measurable changes in whisker length and/or whisker density after exposure to a whisker test condition for a certain duration or number of cycles

2.13
whisker test coupon
piece of metal of specified size and shape that is plated or dipped with a tin finish for the purpose of measuring the propensity for whisker formation and growth

2.14
minimum lead-to-lead gap
minimum gap between leads (terminations)



IEC 2387/13

Figure 6 – Minimum lead-to-lead gap

2.15
matte tin
tin film with lower internal stresses and larger grain sizes typically of 1 μm or greater and carbon content less than 0,050 %

2.16
bright tin
tin film with higher internal stresses and smaller grain size of 0,5 μm to 0,8 μm and carbon content of 0,2 % to 1,0 %

3 Test method for measuring tin whisker growth

3.1 Procedure

Except as specifically noted in this document, the procedures for conducting stress testing and inspections for tin whisker growth as shown in Annex A, shall be used as applicable to satisfy this acceptance standard.

3.2 Test samples

In most cases, individual production components shall be used for the acceptance test. However, for some assembled components with internal tin plated surfaces that cannot be inspected optically, e.g., internal surfaces of cans and hybrid component lids, testing and inspection of piece parts may be necessary. In addition, components with tin or tin alloy surface finishes used in press-fit, socketed applications, or with other compressive mechanical connections, should be qualified in their end use configuration. Additional testing and/or specifications may be needed for testing mechanically loaded components.

3.3 Handling precaution

Careful test sample handling is important in order to avoid possible damage or detachment of whiskers from the test samples. Excessive vibration, impact, or physical contact with the termination finish should be avoided because whiskers may be dislodged. Test sample contamination as a result of improper handling or as a result of the application of a conductive material for SEM inspection should be avoided if the samples are to be returned to the test condition for further exposure, because such material may impact whisker growth behaviour. The procedures outlined in Annex A to limit condensation on the samples should also be followed during elevated temperature-humidity testing since condensation increases the likelihood of surface corrosion.

3.4 Reflow assembly

The board assembly process shall reflect both the influence of typical reflow temperatures and the metallurgical effects of a typical solder material. Components for which the terminations are usually fully wetted, even with a board assembly process at the lower process window limits, are exempted from this test. For example, this applies to:

– nonleaded components;
– flat leaded components.

Since whiskers usually grow only from the unwetted surface finish, it is essential that there is some unwetted area left after the board assembly process. This area shall represent at least 1/3 of the termination surface. Technical justification (documentation) shall be provided that the 1/3 minimum unwetted area requirement has been met, for example statistical EDX analysis, etc. The number of sample terminations inspected needs to be increased due to the reduction of termination area wetted by the board solder. The inspection increase should be based on achieving approximately the same area as an unwetted termination. For example, if only 1/3 of the termination area is unwetted, 3 times as many terminations shall be inspected than for unassembled components, i.e. $96 \times 3 = 288$ per stress test.

The board assembly process will likely be somewhat different than typical production assembly processes because of the requirement for minimum termination wetting. In cases where the acceptance of multiple component types is being assessed by similarity (Tables 2 and 3), it is recommended that board assembly be performed on the component type with the longest terminations in order to promote the presence of an unwetted surface. Table 1 provides some further guidance for the board assembly process that may help to minimize termination wetting. Finally, it is recommended to clean the test board of flux residues before acceptance testing due to the unknown effect of flux residues on whisker growth.

Table 1 – SMT board assembly process guidance for minimum termination wetting[b]

Reflow atmosphere	Air
Flux type	Low activity
Paste alloy	Precondition C: SnPb Rrecondition D: SnAgCu
Stencil	Substantial cut backs from production opening and/or thickness may be required
Reflow profile[a]	SnPb and Pb-free reflow profiles in accordance with Table A.3 and Figure A.2

[a] In some cases it may be necessary to use a peak temperature at the low end of the range in order to avoid substantial wetting of the terminations.

[b] Boards do not need to be electrically functional.

4 Acceptance procedure for tin and tin alloy surface finishes

4.1 Determination of whether a technology, manufacturing process, or similarity acceptance test is required

The acceptance requirements for tin and tin alloy finishes depend on the acceptance testing history of the surface finish. For a surface finish without any acceptance testing history, a rigorous technology acceptance test shall be completed as described in 4.3. If the tin or tin alloy finish has already passed a technology acceptance test, then any change to the manufacturing process or the metallurgy shall be categorized as either a technology change, a manufacturing process change, or a negligible change based on similarity. Table 2 may be used as guidance to differentiate between a technology and a manufacturing process acceptance change. Table 3 shall be used to categorize a change as either a technology change, a manufacturing process change, or a negligible change based on similarity. In addition, Table 3 indicates required testing that is described in detail in Tables 4 to 8. The acceptance procedure for tin and tin alloy surface finishes shall follow the procedural flow outlined in Figure 7. A specific surface finish/mitigation process or change will necessitate a technology or manufacturing process change acceptance unless the change is covered by similarity. Figure 8 shows the typical technology acceptance test flow, using minimum sample size, for multi-leaded components using copper alloy leadframe with post bake mitigation technology.

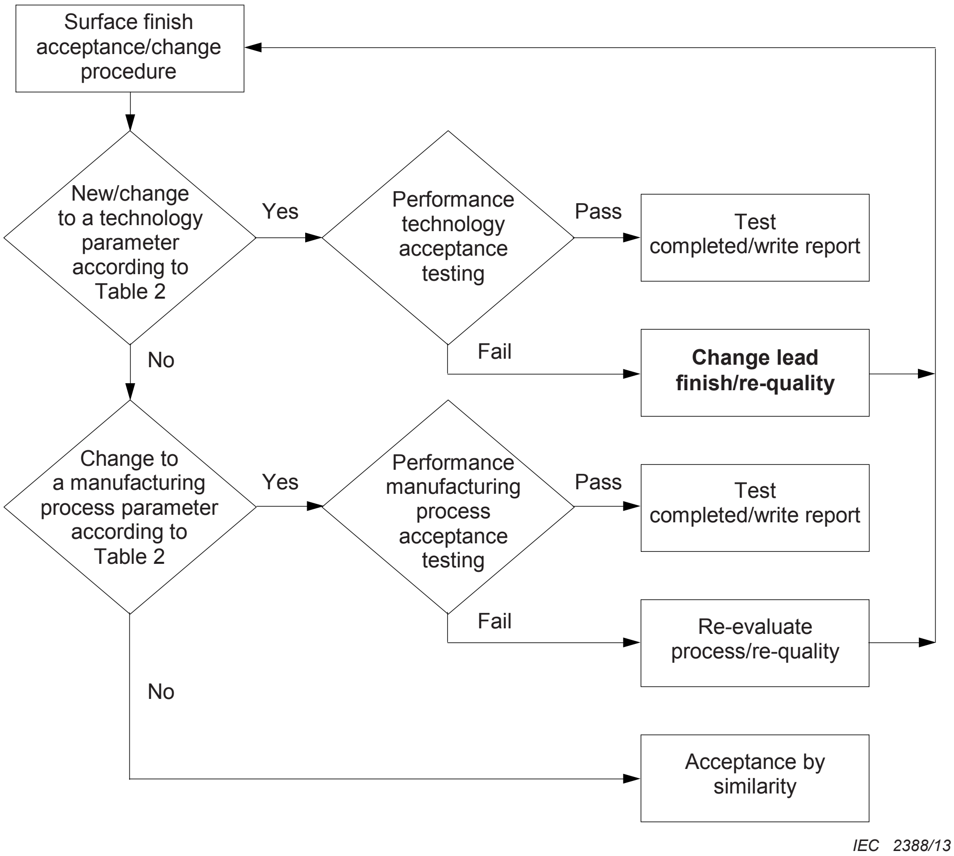


Figure 7 – Flowchart to determine whether a technology acceptance test, a manufacturing process acceptance test or no testing is required on the basis of similarity

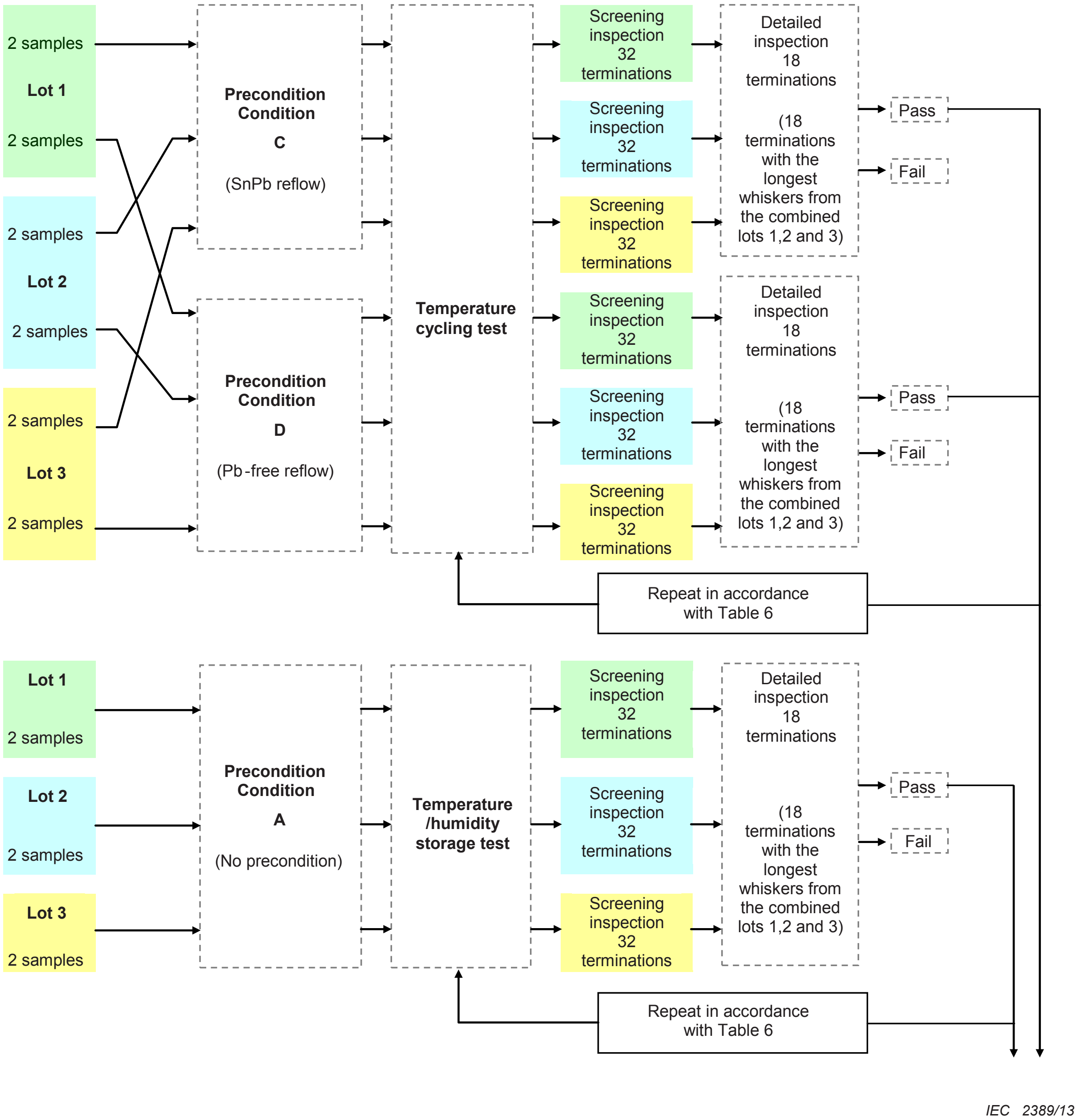


Figure 8 – Technology acceptance test flow for multi-leaded components using copper alloy leadframe with post bake mitigation technology – Surface finish test sample, technology parameters fixed *(1 of 2)*

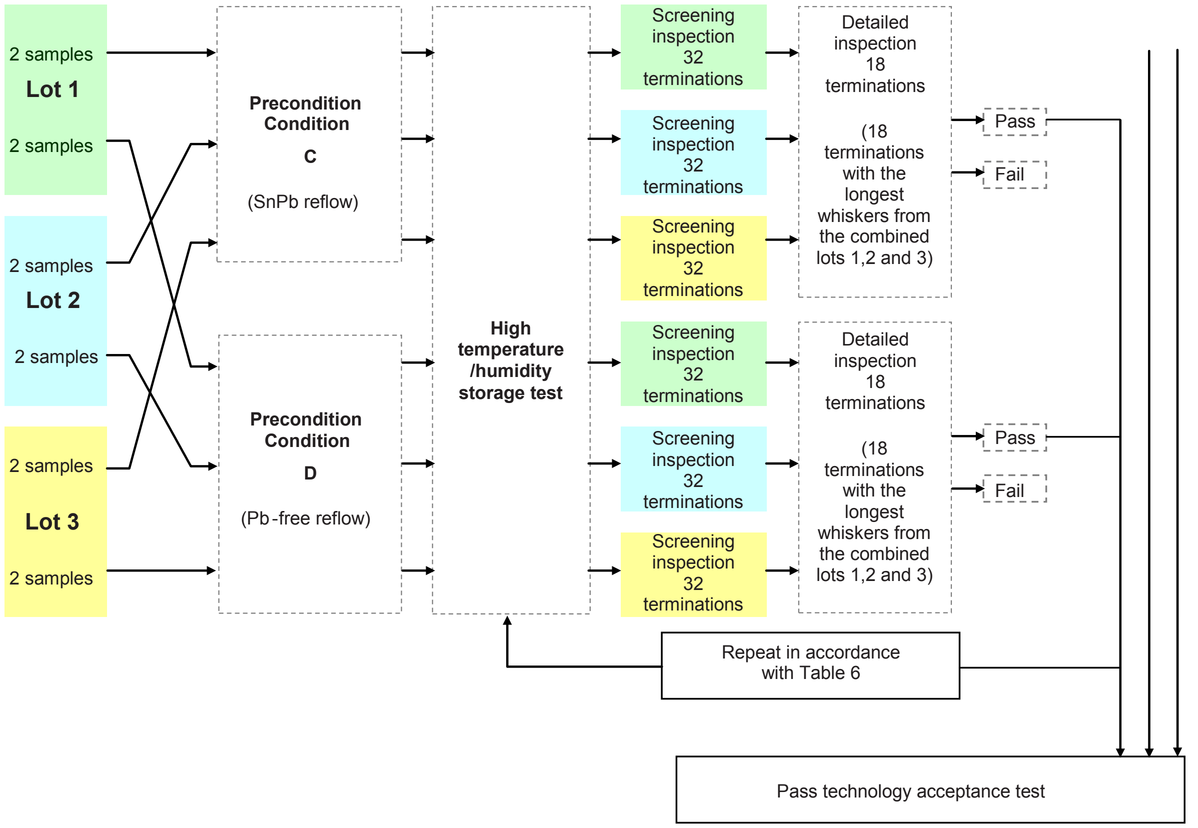


Figure 8 *(2 of 2)*

The acceptance requirements described in this document apply to a specific tin or tin alloy surface finish. The same surface finish may originate from multiple plating lines and be used on multiple component types, as long as the parameters described in Table 2 are the same. For the purposes of this document, a surface finish is defined by the base metal, surface finish composition, surface finish chemistry and manufacturing process, assembly process and component type, and factory or plating process. These categories are listed in the left column of Table 2. Within these categories, there are major parameters called technology parameters and minor parameters called manufacturing process parameters that define the tin or tin alloy surface finish. Any new surface finish shall be submitted for a technology acceptance test. In addition, changes to technology parameters require a new technology acceptance test, and changes to a manufacturing process parameter require a new manufacturing process acceptance test, according to the flowchart in Figure 7.

Table 2 – Surface finish technology and manufacturing process change acceptance parameters

Parameter	Technology parameters	Manufacturing process parameters
Base metal	• base metal composition	• type, e.g., etched or stamped
Surface finish composition	• surface finish alloy composition • surface finish thickness • underplate composition • underplate thickness	
Surface finish chemistry or manufacturing process	• surface finish plating process • process chemistry • underplate process • underplate process chemistry • dip process • dip process chemistry • post bake process parameters • plating bath vendor • major plating process control parameters	• minor plating process control parameters • dip process control parameters
Assembly process and component type		• lead forming process
Factory or plating process	• startup new factory	• new plating equipment

Table 3 lists the technology and manufacturing process change acceptance tests required for parameter changes. The details of the tests are described in Tables 4 to 8. Table 3 also defines those changes that are considered negligible and do not require additional testing, according to the flowchart in Figure 7.

Table 3 – Tin and tin alloy surface finish acceptance test matrix

Technology or manufacturing process parameter	Examples	Qual type[a]	Acceptance tests required		
			TC[b]	T&H	High/ T&H
Base metal					
base metal alloy[c]	base metal, e.g., Cu alloy, FeNi42	T	x	x	x
base metal vendor[d]	supplier A vs. B, same metal	S	–	–	–
leadframe type	etch vs. stamped	P	x	x	x
Surface finish composition					
surface finish alloy	Sn, SnAg3,5, SnBi2-4, SnBi5-7, SnCu1, SnCu3	T	x	x	x
surface finish thickness	change in thickness limits	T	x	x	x
underplate composition	change in underplate composition	T	x	x	x
underplate thickness	change in thickness limits	T	x	x	x
Surface finish chemistry or process					
surface finish plating process	in-line vs. rack vs. barrel, bright vs. matte tin	T	x	x	x
underplate process	change in underplate process	T	x	x	x
process chemistry	MSA, mixed acid, etc.	T	x	x	x
plating bath vendor	supplier A vs. B	T	x	x	x
major plating process window limits	change beyond process window limits for additive levels, metal content, acid content, current density, temperature, impurity levels	T	x	x	x
minor plating process window limits	change within process window limits for additive levels, metal content, acid content, current density, temperature, impurity levels	S	–	–	–
dip process	change of flux, impurity levels, immersion rate, cooling rate, etc.	T	x	x	x
post bake process	change in bake process parameters	T	x	x	x
Assembly process and component style					
lead form	J-lead vs. gull wing	S	–	–	–
lead count	different lead count	S	–	–	–
lead dimension	e.g., 0,25 mm wide, 0,18 mm wide	S	–	–	–
Factory or plating process[e]					
startup new factory	new factory	P[f] T	x x	x x	x x
new plating line (duplicate)	accepted technology/factory/vendor	S	–	–	–
new plating equipment	new plating line, vendor, or relocation of a line	P	x	x	x

[a] T = technology acceptance; P = manufacturing process change acceptance; S = similarity acceptance.

[b] For the manufacturing process change acceptance, the TC test may be omitted if the CTE (coefficient of thermal expansion) of the base metal is > 15 ppm/K. If an underplate is used, the TC may be omitted only if the CTE of both the underplate and base metal is > 15 ppm/K.

[c] Technology acceptance testing is not required for changes to copper alloys if an underplate sufficient to limit copper diffusion into the tin surface finish is used.

[d] Same base metallurgy/chemistry including any flash metal surface plating.

[e] Precautions should be taken as regards maintenance practices, which can result in a change in manufacturing process parameters, which may result in more susceptibility to whisker growth.

[f] A new factory interim release may be granted based on manufacturing process change acceptance completion upon agreement between supplier and user. Full factory release will be after successful completion of the technology acceptance testing.

4.2 Samples

4.2.1 Sample requirements

4.2.1.1 Sample production and surface finish

Production samples and surface finishes shall be used for technology and manufacturing process acceptance testing. The set of production samples used for a single technology or process acceptance test shall be composed of three lots of the same surface finish, according to Tables 4 and 5. The set of production samples used for a single technology or manufacturing process acceptance test shall be taken from three lots of the same surface finish, according to Tables 4 and 5. The required three lots of surface finish may be plated at one-week intervals on the same plating line or may be plated simultaneously on different plating lines within the same factory using the same surface finish, defined by the same technology and process parameters that are listed in Table 2. The same samples shall be used at each inspection or readpoint, as described in 4.3. Component samples for applications with mechanical connections, i.e. press-fit or socketed, etc., should be qualified in the end use configuration.

4.2.1.2 Lead forms

The samples chosen for the test shall be selected with consideration of the lead form. It is not necessary to test every lead form. For IC and lead type components, the gull wing configuration (if applicable) shall be tested. If not applicable, select the lead form that has the most extreme case of tin deformation due to trim and form operations that occur after plating. For other component types, select the product for testing that has the most extreme case of tin deformation due to trim and form operations (if applicable).

4.2.2 Sample size for multi-leaded components with 5 or more leads

Table 4 specifies the minimum quantity of 3 plating lots, 2 samples from each lot per each described precondition treatments (see Table 8), making a total minimum of 18 samples per stress test. When the number of terminations per sample part is less than 16, the number of components shall be increased to meet the minimum required number of termination inspections, in accordance with Table 4.

4.2.3 Sample size for passive and discrete components with 4 leads or fewer

Table 5 specifies the minimum quantity of 3 plating lots, 3 samples from each lot per each described precondition treatments (see Table 8), making a total minimum of 27 samples per stress test.

4.2.4 Additional samples

It is recommended that some samples in addition to the minimum shown in Tables 4 and 5 be included for the high temperature/humidity storage test because of the possibility of surface corrosion, which can result in terminations or components being removed from the whisker inspection. As defined in Clause 2 and discussed in 4.3, terminations or components may be removed from inspection due to surface corrosion. Since terminations or components that are removed due to corrosion shall be replaced in order for the test to be valid, it is beneficial to begin testing with extra samples.

Table 4 – Tin and tin alloy surface finish acceptance test sample size requirements per precondition treatment for multi-leaded component

Stress type	Minimum sampling and inspection requirements per precondition treatment				
	Lots per stress	Samples per lot	Components inspected per readpoint[a]	Screening inspection terminations per readpoint[b]	Detailed inspection terminations per readpoint[c]
Temperature cycling	3	2	6	96	18
Temperature /humidity storage	3	2	6	96	18
High temperature /humidity storage	3	2	6	96	18

[a] Components should be drawn equally from the manufacturing lots, as much as is practicable.

[b] Minimum number of terminations inspected during screening inspection per readpoint (see Annex A).

[c] If whiskers are detected in the screening inspection, then the terminations with the longest whiskers shall be measured in the detailed inspection. The longest whisker is measured and recorded for each termination. If no whiskers are detected in the screening inspection, then no detailed inspection is required, according to Annex A.

Table 5 – Tin and tin alloy surface finish acceptance test sample size requirements per precondition treatment for passive and discrete components with 4 leads or fewer

Stress type	Minimum sampling and inspection requirements per precondition treatment				
	Lots per stress	Samples per lot	Components inspected per readpoint[a]	Screening inspection terminations per readpoint	Detailed inspection terminations per readpoint[b]
Temperature cycling	3	3	9	18	18
Temperature /humidity storage	3	3	9	18	18
High temperature /humidity storage	3	3	9	18	18

[a] Components should be drawn equally from the manufacturing lots, as much as is practicable.

[b] The longest whisker is measured and recorded for each termination. If no whiskers are detected in the screening inspection, then no detailed inspection is required, according to Annex A.

4.3 Test procedures and durations

4.3.1 Preconditioning

The technology acceptance and manufacturing process acceptance testing require that the samples described in 4.2 shall be preconditioned prior to test condition exposure, according to Table 8 and Annex A.

Depending on the base metal of the surface finish and the mitigation method used, different preconditioning is required prior to performing the technology or manufacturing process acceptance test, as described in Table 8. All preconditions indicated in Table 8 for a particular base metal and test condition are required for an acceptance test. Refer to Figure 8 for a typical schematic of the division of multi-leaded components using copper alloy leadframe with post bake mitigation technology from 3 lots.

4.3.2 Test conditions

Tables 6 (technology acceptance) and 7 (manufacturing process acceptance) list the stress tests, test conditions, inspection intervals and total durations required for tin whisker acceptance testing of tin-based surface finishes. Testing shall be carried out in accordance with Tables 6 and 7, unless otherwise detailed in the relevant specification. The user should refer to Annex A for procedures for conducting these tests.

4.3.3 Test durations

Specific inspection intervals and total test durations shall be used as defined in Tables 6 and 7. These inspection intervals and total durations depend on the class level of the product, in accordance with 4.4, in which the component will be used. A particular surface finish may be tested for acceptability in multiple product class levels. The product class affects the inspection intervals and test durations listed in Tables 6 and 7, as well as the failure criteria given in Tables 9 and 10.

4.3.4 Whisker inspection

At each inspection interval listed in Tables 6 and 7, the test samples shall be removed from the stress chamber(s) and inspected by optical microscope and/or SEM according to the procedures specified in Annex A. If optical microscopy is used for screening and measurement of whisker length, then validation of the optical equipment shall be performed in accordance with Annex A prior to inspection of whisker samples.

The same samples shall be used at each inspection readpoint. For example, for a high temperature high humidity test, on a copper base, multi-leaded component with no mitigation, testing would begin with a minimum of 18 samples (2 samples from each of 3 lots for each of the 3 precondition treatments). Consider one particular precondition treatment with 6 corresponding sample parts. At the 1 000 h readpoint, these 6 samples would be removed from the chamber, 96 terminations would be inspected, and the 18 terminations with the longest whiskers shall have the longest whisker on each termination measured. These 6 samples then would be returned to the thermal chamber and exposed for another 1 000 h. Then, these same 6 samples would be removed at the 2 000 h readpoint, the same 96 terminations would be inspected, and the 18 longest whiskers (not necessarily the same as at the previous readpoint) would be measured. This process would repeat until the test is complete.

The time that samples are out of the chamber for inspection and whisker measurement should be kept to a minimum in order to minimize the overall test time and to avoid inducing artifacts into the whisker measurements. If time out of chamber is over 24 h the time shall be reported. (See Clause 6).

4.3.5 Surface corrosion observed during high temperature/humidity testing

If surface corrosion is observed, the termination showing corrosion may be removed from the whisker inspection; any termination removed shall be replaced with another termination to maintain the total required sample size.

If one sample part shows evidence of massive corrosion, that sample may be removed as invalid for the test and replaced with another sample. Therefore, additional samples beyond the minimum required in Tables 4 and 5 may need to be included from the beginning to account for the possibility of removing a corroded sample part from the test.

Any elimination or substitution of sample parts or individual terminations due to corrosion shall be documented with appropriate technical justification (in accordance with Clause 6).

Table 6 – Technology acceptance tests and durations

<table>
<tr><th rowspan="2">Stress type</th><th rowspan="2">Test conditions</th><th rowspan="2">Preconditioning</th><th rowspan="2">Inspection intervals</th><th colspan="2">Total duration</th></tr>
<tr><th>Class 1 and 2 products</th><th>Class 1A products[e,f]</th></tr>
<tr><td rowspan="2">Temperature cycling[a]</td><td>$-55\,^{0}_{-10}$ °C to
$+85\,^{+10}_{0}$ °C ,
air to air;
10 min soak;
~3 cycles/h (typ.)</td><td rowspan="2">in accordance with Table 8</td><td rowspan="2">500 cycles</td><td rowspan="2">1 500 cycles</td><td rowspan="2">1 000 cycles</td></tr>
<tr><td>$-40\,^{0}_{-10}$ °C to
$+85\,^{+10}_{0}$ °C ,
air to air;
10 min soak;
~3 cycles/h (typ.)</td></tr>
<tr><td>Temperature/humidity storage</td><td>30 °C ± 2 °C and
60 % ± 3 % RH[b]</td><td>in accordance with Table 8</td><td>1 000 h</td><td>4 000 h[d]</td><td>1 000 h</td></tr>
<tr><td>High temperature/humidity storage</td><td>55 °C ± 3 °C and
85 % ± 3 % RH[c]</td><td>in accordance with Table 8</td><td>1 000 h</td><td>4 000 h[d]</td><td>1 000 h</td></tr>
</table>

[a] Either temperature cycling test condition may be used.

[b] Previous data generated under uncontrolled ambient conditions may be substituted for this condition.

[c] Previous data generated under higher humidity conditions, e.g., 60 °C and 90 % to 95 % relative humidity (RH), are substitutable for this condition.

[d] Whisker length data for all inspection intervals shall be recorded and be available, upon request, for all technology acceptance tests. The length of the longest whiskers at each inspection interval, from the 18 terminations detailed inspection, shall be plotted against the inspection time interval.

[e] See 4.4 for definitions of class levels.

[f] For class 1A products using low CTE (< 15 ppm/K , e.g., alloy 42) leadframe, only the temperature cycling test shall be performed for technology acceptance.

Table 7 – Manufacturing process change acceptance tests and durations

Stress type	Test conditions	Preconditioning	Total duration	
			Class 1 and 2 products	Class 1A products[d]
Temperature cycling[a]	$-55\,^{0}_{-10}$ °C to $+85\,^{+10}_{0}$ °C, air to air; 10 min soak; ~3 cycles/h (typ.)	in accordance with Table 8	500 cycles	500 cycles
	$-40\,^{0}_{-10}$ °C to $+85\,^{+10}_{0}$ °C, air to air; 10 min soak; ~3 cycles/h (typ.)		500 cycles	500 cycles
Temperature/humidity storage	30 °C ± 2 °C and 60 %± 3 % RH[b]	in accordance with Table 8	1 500 h	1 000 h
High temperature/humidity storage	55 °C ± 3 °C and 85 % ± 3 % RH[c]	in accordance with Table 8	1 500 h	1 000 h

[a] Either temperature cycling test condition may be used.

[b] Previous data generated under uncontrolled ambient conditions may be substituted for this condition.

[c] Previous data generated under higher humidity conditions, e.g., 60 °C and 90 % to 95 % RH, are substitutable for this condition.

[d] For class 1A products using low CTE (< 15 ppm/K , e.g., alloy 42) leadframe, only the temperature cycling test shall be performed for manufacturing process change acceptance.

Table 8 – Preconditioning for technology/ manufacturing process change acceptance testing

Base metal alloy	Mitigation technology	Test condition	Precondition treatment[a,b,c]
Copper alloys	none	temperature/humidity storage	required for each test condition: A (no precondition) B + C (storage + SnPb reflow) B + D (storage + Pb-free reflow)
		high temperature/humidity storage	
		temperature cycling	
	Ni barrier Ni > 1,25 µm	temperature/humidity storage	A (no precondition) only
		high temperature/humidity storage	A (no precondition) D (Pb-free reflow)[d]
		temperature cycling	A (no precondition) D (Pb-free reflow)[d]
	other underplate process or post bake process	temperature/humidity storage	A (no precondition) only
		high temperature/humidity storage	C (SnPb reflow) D (Pb-free reflow)[d]
		temperature cycling	C (SnPb reflow) D (Pb-free reflow)[d]
FeNi42 (e.g., alloy 42)	none	temperature/humidity storage	required for each test condition: A (no precondition) C (SnPb reflow) D (Pb-free reflow)
		high temperature/humidity storage	
		temperature cycling	

[a] Preconditioning treatments in accordance with Annex A prior to indicated stresses in Tables 6 and 7.

[b] Reflow assembly is optionally allowed for conditions C and D using the optional preconditioning reflow temperatures from Table A.3. If reflow assembly is used, the number of sample terminations inspected may need to be increased due to the reduction of the termination area wetted by the board solder. The inspection increase should be based on achieving approximately the same area as an unwetted termination. Subclause 3.4 describes the details for the reflow assembly process.

[c] The + symbol indicates sequential preconditioning in the order listed.

[d] If no underlay material, such as nickel or silver, is used or no annealing tin matte heat treatment is used, then condition B (4 weeks room ambient storage) shall be used before conditions C and D.

4.4 Determination of the class level for testing

The class level indicates the test program (test duration and whisker length criteria) used for the surface finish technology acceptance testing. Product classes shall be agreed to between supplier and user. General guidelines for product classes are given in the following but may not apply in all cases:

Class 3: Mission/life critical applications such as military, aerospace and medical applications

- pure tin and high tin content alloys are not typically acceptable.

Class 2: Business critical applications such as telecom infrastructure equipment, high-end servers, automotive, etc.

- a whisker mitigation practice is expected unless otherwise agreed between supplier and user;
- long product lifetimes and minimal downtime;
- products such as disc drives typically fall into this category;
- breaking off of a tin whisker is a concern.

Class 1: Industrial / consumer products

- medium product lifetimes;
- no major concern with tin whiskers breaking off.

Class 1A: Consumer products

- short product lifetimes;
- minimal concern with tin whiskers.

NOTE Examples of whisker mitigation practice can be found in JEDEC/IPC JP002.

5 Acceptance criteria

5.1 General

Whisker length measurements shall be made at each inspection interval and at the total test duration listed in Tables 6 and 7, according to procedures in Annex A. Each of these measurements shall be compared to the maximum allowable tin whisker length in Table 9 for technology acceptance testing and Table 10 for manufacturing process acceptance testing. Any measurement of whisker length that exceeds the appropriate maximum allowable whisker length in Table 9 for technology acceptance testing, or Table 10 for manufacturing process acceptance testing, results in a failure of the surface finish that is being tested. Specifically, a single tin whisker on a single termination that exceeds the appropriate failure criterion in Table 9 or 10 constitutes a failure of the surface finish technology or manufacturing process under test. The appropriate failure criterion or maximum allowable whisker length depends on the product class determined with guidance from 4.4. It is possible for a surface finish to pass 1 or 2 classes while failing others. For instance, a surface finish could pass the class 1A technology acceptance test, but fail the class 1 and class 2 tests.

Generic data on long established tin surface finish manufacturing processes with reliable field histories can be substituted with agreement between supplier and user.

5.2 Through-hole lead termination exclusions

Large through-hole devices may have damage at the ends of the lead terminations due to trim operations. In this case, any whiskers observed within a distance of 2,5 mm from the trimmed lead end may be discounted. Any whiskers observed more than 2,5 mm from the trimmed lead end shall be included in the acceptance analysis.

Examples of devices subject to this exclusion include: axial devices, bridges, and power package devices similar to a package style P-SFM-T3 (TO-220).

This exclusion is not to be used for devices that have a final trim and form that will be assembled as is with no part of the device discarded after soldering, nor is it to apply to any dambar cut area.

Table 9 – Technology acceptance criteria for maximum allowable tin whisker length

Considerations (component type, lead pitch or operating frequency)	**Maximum allowable whisker length**			
	Class 3	**Class 2**	**Class 1**	**Class 1A**
2-lead SMD components	pure tin and high tin content alloys are not typically allowed	40 µm for temperature/humidity storage and high temperature/humidity storage 45 µm for temperature cycling	67 µm[a]	50 µm for temperature cycling and high temperature/humidity storage 20 µm for temperature/humidity storage
Multi-leaded components			67 µm[a]	
High frequency components[b]			50 µm	
Components with a minimum lead-to-lead gap > 320 µm			100 µm	75 µm

[a] This spacing accounts for up to 0,05 mm bent leads. The maximum of the 67 µm accounts for adjacent discrete components.

[b] It is reported that the susceptibility to electrical performance degradation associated with tin whiskers increases with frequency (RF components > 6 GHz, or digital components T_{rise} < 59 ps).

Table 10 – Manufacturing process change acceptance criteria for maximum allowable tin whisker length

Considerations	**Stress type**	**Maximum allowable whisker length**		
		Class 2	**Class 1**	**Class 1A**
Components with a lead-to-lead gap ≤ 320 µm	**temperature cycling**	45 µm	50 µm	50 µm
	temperature/humidity storage	20 µm	20 µm	20 µm
	high temperature/humidity storage	20 µm	20 µm	50 µm
Components with a minimum lead-to-lead gap > 320 µm	**temperature cycling**	45 µm	50 µm	50 µm
	temperature/humidity storage	20 µm	40 µm	75 µm
	high temperature/humidity storage	20 µm	40 µm	75 µm

6 Reporting of results

6.1 General requirements

At the conclusion of the acceptance testing, a report of the background information and findings shall be provided. This report shall contain all of the information described in Clause 6, as applicable. Additional information may be included at the supplier's discretion or by agreement between supplier and user.

6.2 Description of the surface finish, defined by technology and process parameters in Table 2

The following descriptions of surface shall be included:

- the details of the mitigation process used on the test samples (in accordance with Tables A.5 and A.6);
- the component type, base metal, under layer plating (if any), and surface finish material(s);
- the plating and under layer plating (if any) thickness.

6.3 Samples and preconditioning

The following information shall be included:

- the date of plating of each lot and lot identification;
- the precondition treatment and preconditioning temperature profile details;
- the date of preconditioning.

6.4 Acceptance testing

The following information shall be included:

- the type of qualification being performed (technology vs. manufacturing process);
- for a manufacturing process acceptance test, provide a reference to the related technology acceptance test;
- the stress conditions (including inspection intervals and duration) and sample sizes utilized in acceptance testing;
- the acceptance criteria utilized and product class;
- the inspection equipment details including magnifications used;
- the optical inspection qualification data in accordance with A.4, if optical inspection is utilized;
- a table that lists the longest whisker from 18-termination areas inspected (in accordance with Table A.4);
- optical and/or SEM results for each inspection termination per stress condition and interval (in accordance with Tables A.5 and A.6), including maximum whisker length and photograph results;
- as a minimum, photograph results on the longest whisker (or no growth if no whisker is present), in accordance with each precondition treatment, per stress condition;
- the identification and inspection results, including maximum whisker length and typical photographs, of sample parts and/or terminations discounted or removed from whisker inspection due to corrosion;
- in cases where there is an agreement between customer and suppliers that corrosion is present all whiskers observed shall be discounted on the corroded sample or termination;
- the identification of any sample parts and/or terminations discounted due to corrosion;
- the conclusion of whether the surface finish has passed or failed the test.

7 On-going tin whisker evaluation

Suppliers shall establish a system to periodically evaluate the performance of the surface finish manufacturing processes for whisker generation. The specifics of this system are left to the supplier. The following minimum guidelines are suggested:

– a representative sample of components taken periodically, as determined by the supplier, should be evaluated for each surface finish technology;
– the storage conditions for these components should include a relative humidity of 60 % or greater. Using the temperature/humidity storage test conditions of Tables 6 to 8 is preferred;
– the samples should be inspected for whiskers 6 months from the date of plating;
– results should be compared to baseline measurements. If these are exceeded, the supplier should take appropriate corrective actions.

Annex A
(normative)

Test method for measuring whisker growth on tin and tin alloy surface finishes of semiconductor devices

A.1 Overview

The predominant terminal finishes on electronic components have been SnPb alloys. As the industry moves toward Pb-free components and assembly processes, the predominant terminal finish materials will be pure Sn and alloys of Sn, including SnBi and SnAg.

Pure Sn and Sn-based alloy electrodeposits and solder-dipped finishes may grow tin whiskers, which could electrically short across component terminals or break off the component and degrade the performance of electrical or mechanical parts.

The methodology presented in Annex A (see Figure A.1 for process flow), is applicable for studying tin whisker growth from finishes on semiconductor devices containing a predominance of tin (Sn). This test method may not be sufficient for applications with special requirements, e.g., military or aerospace. Additional requirements may be specified in the appropriate requirements document.

The purpose of Annex A is to:

– provide an industry-standardized suite of tests for measurement and comparison of whisker propensity for different plating or finish chemistries and processes;
– provide a consistent inspection protocol for tin whisker examination;
– provide a standard reporting format.

A.2 Disclaimer

Annex A is not to be used as a standalone for qualification purposes. It contains a suite of recommended tin whisker growth tests. If these common tests are adopted, then the industry can collect common and comparable data that may improve the understanding of the fundamentals of whisker growth and allow comparisons between technologies. Tests in this annex may be changed in the future as a better understanding of the mechanisms causing tin whisker growth is developed.

Based on a variety of testing and data review from around the globe, three test conditions have been identified that appear to be suitable for monitoring tin whisker growth. The three test conditions include two isothermal conditions with controlled humidity and a thermal cycling condition. However, these test conditions have not been correlated with longer environmental exposures of components in service. Thus, there is at present no way to quantitatively predict whisker lengths over long time periods based on the lengths measured in the short-term tests described in this document. At the time of writing, the fundamental mechanisms of tin whisker growth are not fully understood and acceleration factors have not been established. However until such time as acceleration factors are determined, all acceptance requirements for commercial tin finishes are provided in this standard. Certain applications, e.g., military or aerospace, may require additional and/or different tin whisker tests or evaluations.

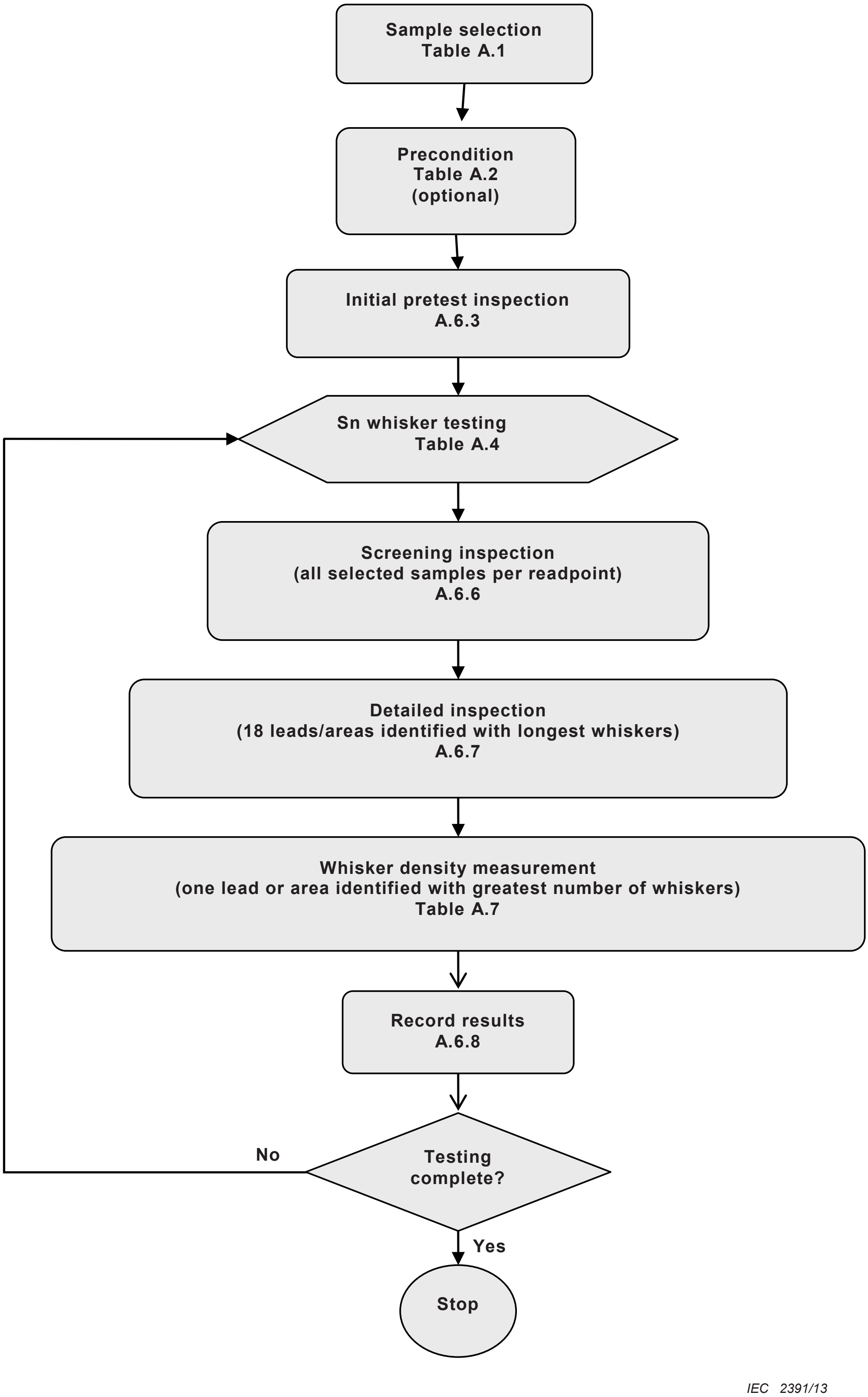


Figure A.1 – Process flow for Sn whisker testing

A.3 Apparatus

A.3.1 Temperature cycling chambers

Temperature cycling chamber(s) shall be air to air, and capable of cycling from $-55\,^{0}_{-10}$ °C to $+85\,^{+10}_{0}$ °C or from $-40\,^{0}_{-10}$ °C to $+85\,^{+10}_{0}$ °C. The temperature cycling chamber(s) shall be able to satisfy the cycle conditions defined in Tables 4 and 5.

A.3.2 Temperature humidity chambers

Temperature-humidity (T&H) chambers shall be capable of functioning in a non-condensing 55 °C ± 3 °C, 85 % ± 3 % RH and 30 °C ± 2 °C, 60 % ± 3 % RH environment.

The elevated temperature–humidity condition of 55 °C ± 3 °C, 85 % ± 3 % RH is close to the condensation point. If water condenses on the tin finish during environmental exposure, the condensed moisture and resulting corrosion may affect the final test results. To prevent condensation in the T&H chamber, the chamber dry-bulb temperature shall exceed the wet-bulb temperature at all times by not less than 2,4 °C (or equivalent for electronic sensors). Before opening of the chamber door for loading and unloading, the chamber temperature and humidity should be ramped down sufficiently close to room ambient (recommended within 10 °C and 10 % RH) to prevent condensation on the test samples and chamber walls.

During operation, condensation is most likely to occur on the T&H test chamber walls and ceiling; therefore, it is recommended that the test samples be sufficiently shielded from any condensed water that may drip from the chamber ceiling and/or walls onto the samples.

When loading the test samples into the T&H test chamber, the sample temperature shall be sufficiently higher than the chamber ambient temperature to avoid condensation on the test samples. It is recommended that the test samples and all sample trays or holders be preheated (to a temperature equal to the test temperature of the T&H test chamber) in a dry-bake oven prior to loading them into the T&H test chamber. Frequent wet-bulb maintenance is required for proper control of this test condition.

A.3.3 Optical stereomicroscope (optional)

The optical stereomicroscope shall possess adequate lighting capable of 50X to 150X magnification and be capable of detecting whiskers with a minimum length of 10 μm, in accordance with A.4. If tin whiskers are measured with an optical system, then the system shall have a stage that is able to move in three dimensions and rotate, such that whiskers can be positioned perpendicular to the viewing direction for measurement.

A.3.4 Optical microscope (optional)

The optical microscope shall possess adequate lighting capable of 100X to 300X magnification and be capable of measuring whiskers with a minimum length of 10 μm, in accordance with A.4. For tin whisker measurements, the optical system shall have a stage that is able to move in three dimensions and rotate, such that whiskers can be positioned perpendicular to the viewing direction for measurement.

A.3.5 Scanning electron microscope

Scanning electron microscopes (SEM) shall be capable of at least 250X magnification. An SEM fitted with an X-ray detector is recommended for elemental identification.

A.3.6 Convection reflow oven (optional)

Convection reflow systems shall be capable of achieving the reflow profiles of Table A.3.

A.4 Validation of optical microscopy equipment

A.4.1 Overall criteria

Validation of the capability of the optical equipment which is used for screening inspection and/or whisker length measurement is required.

The capability of the optical inspection equipment and the associated optical process shall be validated in accordance with A.4.2, A.4.3, and A.4.4 using reference samples inspected and characterized by an SEM. This validation process ensures that the optical equipment and the attendant inspection process can detect whiskers and result in an accurate assessment of the whisker lengths and densities.

The same optical equipment can be used for the two different tasks (screening inspection in accordance with A.6.6 and detailed whisker measurements in accordance with A.6.7). However, in this case the equipment shall be validated independently in accordance with A.4.2, A.4.3, and A.4.4.

If the optical inspection equipment or the optical measurement equipment fails to meet the requirements in A.4.2, A.4.3, and A.4.4, the optical system has failed the validation test for the relevant intended purpose. In this case the optical equipment, the fixturing, the lighting, magnification, and/or viewing angle may be adjusted and the validation procedure repeated for the new configuration. A system need only be re-validated if there is a change in the optical equipment or the inspection process.

NOTE 1 “Optical equipment” is the composite of an optical viewing system, sample retention and manipulation fixtures and lighting.

NOTE 2 As an inspection tool, stereomicroscopes have several advantages over binocular microscopes, and are essential for the screening inspection process. One important advantage is in depth perception. Stereomicroscopes have two separate optical paths. This makes depth perception and three-dimensional viewing of an object possible. Stereomicroscopes also offer long working distances and relatively large fields of view. These attributes make them ideal for whisker inspection.

A.4.2 Capability of whisker detection

The capability of the optical system used for whisker screening inspection shall be verified by following the screening inspection protocols in A.6. The usage of a stereomicroscope is required for the screening inspection process. A minimum whisker length of 10 μm shall be detectable with the optical system used for inspection.

To verify this capability, ten terminations or coupon areas that have whiskers, preferably using samples containing whiskers 10 μm to 20 μm in length and ten terminations or coupon areas without whiskers greater than 10 μm in length, shall be identified using the standard screening procedure and the optical equipment to be validated. The SEM shall then be used to verify the correctness of these selections by confirming that no whiskers greater than 10 μm are present on the ten terminations that were found by the optical system to have no whiskers and further confirming that whiskers of at least 10 μm are present on the ten terminations designated by the optical system as having whiskers greater than or equal to 10 μm. The system passes if the following criterion is met:

– in all cases, the correct distinction is made between terminals or coupon areas with whiskers from those without.

If whiskers of 10 μm to 20 μm are detected in the SEM but not with the optical microscope, then validation of the optical system for whisker detection capability has failed.

The measurements taken to validate the optical system and the results of the validation process should be documented for reference.

NOTE 1 A sample with whiskers having lengths of 10 μm to 20 μm can frequently be created by performing 500 to 1 000 thermal cycles, as defined in Table A.4, on a matte-tin plating or finish. If needed, a sample with a low density of whiskers can frequently be created by performing an isothermal aging using matte-tin over Cu, as defined in Table A.4, for 3 000 h to 4 000 h.

NOTE 2 Test samples identified as containing areas both with and "without" whiskers could, with time during storage, nucleate and grow new whiskers or continue to grow existing whiskers. Therefore, reference samples identified and characterized for whisker-detection capability cannot be used at a later time for additional optical system validations unless all samples are once again re-characterized by SEM inspection, and found to still meet the test sample requirements intended for the detection-capability process.

NOTE 3 Capturing a low magnification image of the region containing the measured whisker can be used as an aid for finding and identifying the exact whisker of interest. This can be done with either optical or SEM techniques.

A.4.3 Capability of whisker length measurement

The capability of the optical system to accurately measure whisker lengths shall be validated by comparison of optical measurements to those made with an SEM. This comparison shall be made on samples with whisker lengths ranging from 10 μm to 50 μm (see Note 1). The minimum number of whiskers measured in this validation shall be 30. The individual whiskers measured shall be the same for both systems so that direct comparisons of measured lengths can be made. The optical system passes if the following criterion is met:

– for the same whisker, the maximum whisker length measured with the optical system differs by less than 5 μm on average and by less than 10 μm for any particular whisker from the measurements taken in the SEM.

The measurements taken to validate the optical system and the results of the validation process should be documented for reference.

NOTE 1 A sample with whiskers having lengths of 10 μm to 50 μm can frequently be created by performing 1 000 to 2 000 thermal cycles, as defined in Table A.4, on a matte-tin plating or finish.

NOTE 2 Reference samples used for whisker length as well as density measurements can, with time during storage, nucleate and grow new whiskers or continue to grow existing whiskers. Therefore, reference samples identified and characterized for the whisker length/density capability cannot be used at a later time for additional optical system validations unless all samples are once again re-characterized by SEM inspection.

A.4.4 Capability of whisker density measurement

The capability of the optical system to accurately measure the density of whiskers shall be validated by comparison of the optical measurements with those made with an SEM. This comparison shall be made on six separate samples with whiskers ranging from 10 μm to 50 μm in length (refer to Note 1 of A.4.3). Preferably, at least one sample will have a high density of whiskers and at least one sample will have a low density of whiskers, according to Table A.7. The six samples can be six separate terminations on one electronic component, six separate terminations from multiple different electronic components, or can be six different areas on one or more coupons. The samples used for validating whisker density measurement capability can be the same as those used for the whisker length measurement capability (A.4.3). For each sample, the number of whiskers greater than 10 μm in length shall be measured with both systems within the same viewing area. The optical system passes if the following criterion is met:

– the whisker density measured with the optical system is within 20 % of that measured with an SEM.

The measurements taken to validate the optical system and the results of the validation process should be documented for reference.

A.5 Sample requirements and optional preconditioning

A.5.1 Acceptance requirements

For acceptance requirements of tin finishes for commercial use, the relevant test conditions, readpoints, and durations are given in Clause 4. For evaluating the whisker propensity of tin finishes for other purposes (e.g., scientific study, preliminary evaluations of various platings, etc.), it is recommended that all three conditions defined in Table A.4 be used and that the durations given in Table 6 for class 1 and 2 products be used. In addition, each test condition is to be performed independently on separate samples.

A.5.2 Scientific studies

Test coupons may be used for scientific studies.

A.5.3 Test coupons

For comparison purposes, if using coupons, a total inspection area of at least 75 mm^2 on at least 3 coupons is required for each test condition. For small coupons, it is recommended that there be sufficient coupons so that the total area inspected adds up to a minimum of 75 mm^2, as described in Table A.1.

Table A.1 – Test sample size requirements per precondition treatment for coupons

Sample type	Finished area[a]	Minimum number of samples	Minimum total inspection area for screening inspection	Minimum inspection surface area per sample for screening inspection	Minimum total number of inspection areas for screening inspection[b]	Detailed inspection (number of areas per readpoint)[b]
small coupons	< 25 mm^2	3	75 mm^2	top and two sides of coupon	75 mm^2 divided by (plated area on top and 2 sides of coupon)	9
large coupons	≥ 25 mm^2	3	75 mm^2	top and two sides up to a total of 25 mm^2	3	9

[a] See Figure A.6 for detailed definition of the plated/finished area for inspection.

[b] Each area for detailed inspection should be a minimum of 1,7 mm^2.

The same components or coupons evaluated for each test condition may be evaluated at all sequential readouts, including the final readout. Hence, to study a single finish, a minimum of 9 coupon samples are required to complete the three test conditions. Alternatively, the test may be started with a sufficient quantity of test samples equalling the minimum number of samples required per readout times the number of readouts. If a more accurate determination of growth kinetics is needed, it is recommended that the same test samples be used for each sequential readout instead of using re-populated samples.

A.5.4 Optional test sample preconditioning

A.5.4.1 Optional test sample preconditioning treatments

Table A.2 lists optional test sample preconditioning treatments that are recommended prior to all subsequent Sn whisker growth tests.

Table A.2 – Optional preconditioning treatments for tin whisker test samples

Condition	Preconditioning temperature exposure	Thermal profile exposure	Use guidelines
A	none	normal ambient exposure	intended to test for whisker growth under ambient temperature/humidity storage
B	room temperature storage for a minimum of 4 weeks after the finish is applied	15 °C to 30 °C 30 % to 80 % RH	intended for samples without under-plating or post bake mitigation before exposure to high temperature/humidity storage, temperature cycling or preconditioning in accordance with conditions C or D
C	SnPb temperature preconditioning	SnPb profile in accordance with Table A.3	intended to test for whisker growth after thermal exposure to SnPb SMT assembly temperatures (backward compatibility)
D	Pb-free temperature preconditioning	Pb-free profile in accordance with Table A.3	intended to test for whisker growth after thermal exposure to Pb-free SMT assembly temperatures (Pb-free compatibility)

A.5.4.2 Optional test sample preconditioning profiles

NOTE The profiles in A.5.4.2 utilize a lead or coupon temperature reference.

Test sample preconditioning profile information is shown in Table A.3 and Figure A.2. All profile criteria reference either the lead or solder joint temperature for components or the surface temperature for coupons. For the profile and the preconditioning process itself, it is recommended that non-metallized carriers or printed circuit boards be used to hold the samples during the reflow process. For components with leads, the orientation of the component shall be in the “live bug” configuration (i.e., leads down touching the carrier or board).

Table A.3 – Optional preconditioning reflow profiles [a]

Profile feature	SnPb profile	Pb-free profile
average ramp-up rate ($T_{s,max}$ to T_{peak})	3 °C s^{-1} max.	3 °C s^{-1} max.
preheat: – temperature min. ($T_{s,min}$) – temperature max. ($T_{s,max}$) – time ($T_{s,min}$ to $T_{s,max}$) (t_s)	 100 °C 150 °C 60 s to 120 s	 150 °C 200 °C 60 s to 120 s
time maintained above: – temperature (T_L) – time (t_L)	 183 °C 60 s to 120 s	 217 °C 60 s to 120 s
lead or solder joint temperature (T_{peak})	200 °C to 220 °C [b]	245 °C to 260 °C [c]
average ramp-down rate (T_{peak} to $T_{s,max}$)	6 °C s^{-1} max.	6 °C s^{-1} max.
time duration from 25 °C to peak temperature	6 minutes max.	8 minutes max.

[a] All temperatures refer to lead or solder joint temperature for components or the surface temperature for coupons.

[b] Maximum temperature of 220 °C ensures that the finish is not melted (i.e., melting point of pure Sn is 232 °C).

[c] Minimum temperature of 245 °C ensures that the finish is melted.

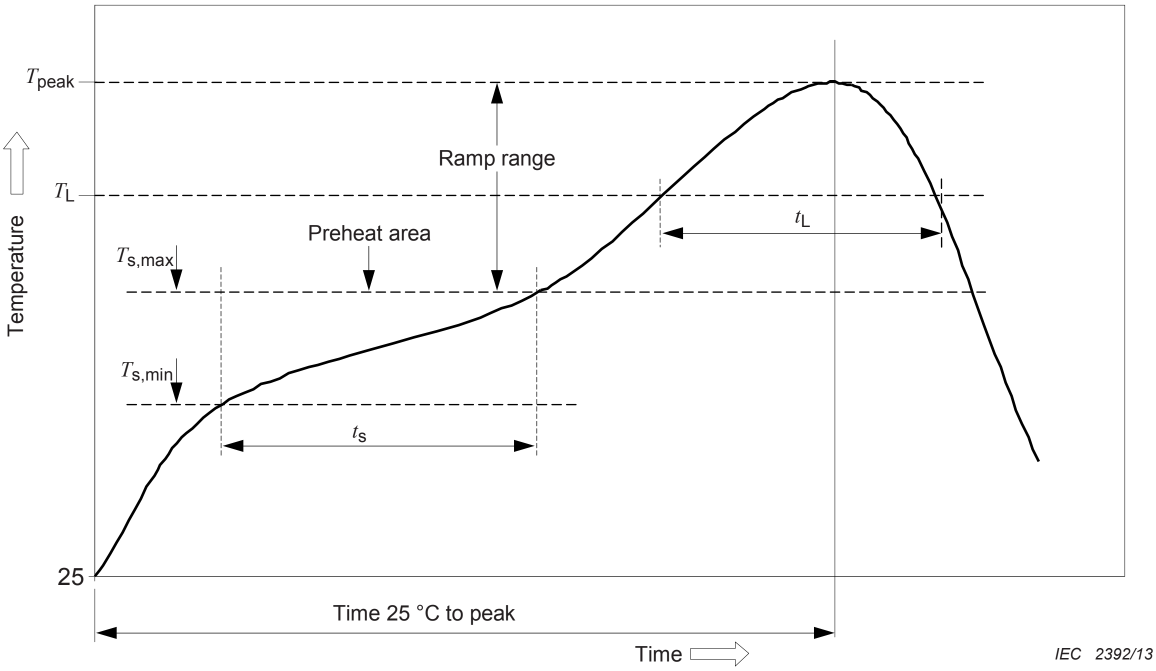


Figure A.2 – Optional preconditioning reflow profile

A.6 Whisker inspection, length measurement and test conditions

A.6.1 General principles

The whisker inspection procedure includes three parts: (1) the initial pre-test inspection, (2) the screening inspection, and (3) the detailed inspection. The initial inspection should be performed once before the test samples are exposed to any test condition. The screening inspection should be performed at each readout. If whiskers are detected in the screening inspection, then the detailed inspection should be performed at that readout. The whisker inspections can be performed using either an SEM or a validated optical system meeting the conditions as outlined in A.4.

A.6.2 Handling

When handling test samples, care shall be taken to avoid contact with the finish which may result in the detachment of whiskers. For SEM inspection, a conductive material to attach the test sample to the SEM work holder to prevent charging is recommended; however, if the same test samples will be inspected at each readout and then returned to the test condition for further exposure, conductive sputter coating, such as C, Pt, or Au, shall not be deposited to aid SEM inspection. If the test samples will not be returned to the test condition, then a conductive coating may be used to reduce sample charging.

A.6.3 General inspection instructions

The screening (A.6.6) and detailed inspections (A.6.7) for whiskers shall include inspection for whisker patterns and relationships (alignments) between whiskers and sample features or between whiskers and irregularities. Irregularities are extrinsic (acquired) features which deviate from the original, ideally (perfectly) plated surface, particularly those features that occur as a result of post-plating mechanical operations or deterioration of the plated surface.

During inspection, particular attention should be paid to the occurrence of corrosion, surface scratches, tool/clamping marks, edges and surfaces created by punching or shearing operations, heat affected zones or solder-to-plated surface boundaries (created during assembly). The presence of special relations between whiskers and irregularities should be recorded in Table A.6. In addition, it is strongly recommended that images are taken to document any relationship observed between whiskers and features and/or irregularities.

Figure A.3 shows examples of corrosion irregularities (in this instance the corrosion occurs in areas adjacent to other irregularities created by shearing and punching operations that expose copper base metal).

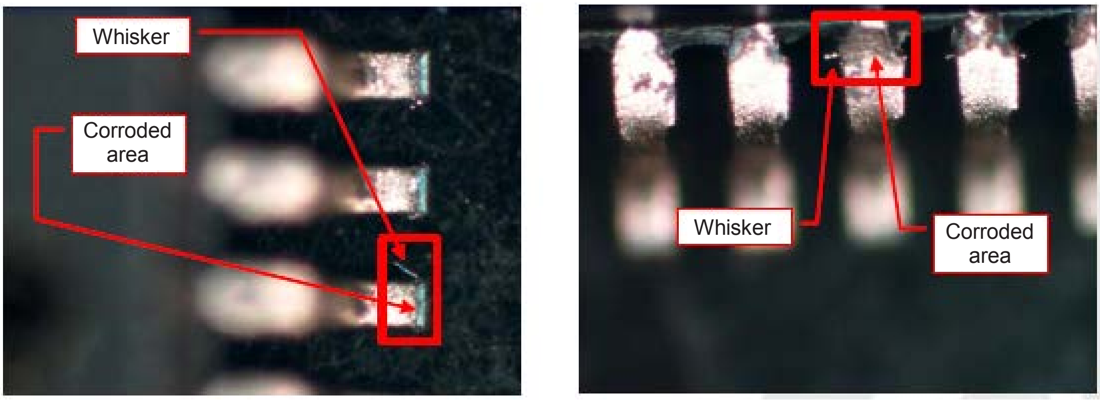


Figure A.3 – Examples of whiskers in areas of corrosion

A.6.4 Initial pretest inspection

Prior to any test condition exposure, an initial optical or SEM inspection should be conducted and documented to determine if whiskers are present. The same procedure used for the screening inspection, described in A.6.6, shall be followed.

A.6.5 Test conditions

Test conditions used for assessing tin whisker growth are listed in Table A.4. These test conditions represent a minimum set of conditions that shall be used to assess the propensity for tin whisker growth on any given tin finish under study.

Table A.4 – Tin whisker test conditions

Stress type	Test conditions
temperature cycling	minimum temperature $-55\ ^{0}_{-10}$ °C or $-40\ ^{0}_{-10}$ °C maximum temperature $+85\ ^{+10}_{0}$ °C , air to air; 10 min soak; ~3 cycles h^{-1}
ambient temperature / humidity storage	30 °C ± 2 °C and 60 % ± 3 % RH
high temperature / humidity storage	55 °C ± 3 °C and 85 % ± 3 % RH

A.6.6 Screening inspection

A.6.6.1 Screening requirement

The screening inspection shall be performed for all samples at each readout following exposure to any test condition. The intent is to efficiently inspect the entire sample population and identify those leads, terminations, or coupon areas that contain whiskers for further detailed inspection.

A.6.6.2 Components

Components shall be inspected using either an optical system meeting the requirements of A.4 or an SEM. If the screening inspection is performed with an optical system, a minimum magnification of 50X is required. For whisker verification, a higher magnification is recommended. If the screening inspection is performed with an SEM, a minimum magnification of 250X is required. If whiskers are not detected during the screening inspection, then a detailed inspection is not required at that readpoint. If whiskers are detected during the screening inspection, then a minimum of 18 areas that appear to have the longest tin whiskers shall be identified for detailed inspection.

A.6.6.3 Coupons

For coupons larger than 25 mm^2, a minimum of 3 coupons, in accordance with Table A.1, shall be inspected using either an optical system meeting the requirements of A.4 or an SEM. On each of these 3 coupons, a minimum area of 25 mm^2 shall be screened, including at least two edges of at least 3 mm in total length. For coupons smaller than 25 mm^2, additional coupons shall be screened, such that the total area screened is a minimum of 75 mm^2. If the screening inspection is performed with an optical system, a minimum magnification of 50X is required. For whisker verification, a higher magnification is recommended. If the screening inspection is performed with an SEM, a minimum magnification of 250X is required. If whiskers are not detected during the screening inspection, then a detailed inspection is not required at that readpoint. If whiskers are detected during the screening inspection, then a minimum of three areas of 1,7 mm^2 on each coupon that appear to have the longest tin whiskers shall be identified for detailed inspection. These three areas from each sample shall be evaluated following the detailed inspection procedure in A.6.7.

A.6.7 Detailed inspection

A.6.7.1 Inspection requirements

The detailed inspection shall be performed on terminations or areas identified in the screening inspection. If whiskers are not observed in the screening inspection then the detailed inspection is not required. For test samples that exhibit whiskers, 3 terminations or 3 areas per sample and a minimum of 6 components for multi-leaded devices, 9 passive/discrete components with 4 leads or fewer or 3 coupons shall be inspected. A scanning electron microscope or a validated optical system (see A.4) shall be used for the detailed inspection. For SEM inspections, a minimum magnification of 250X shall be used and for optical systems a minimum magnification of 50X shall be used. For the whisker length measurements themselves, a magnification higher or lower than that used for inspection may be required, such that the whisker being measured approximately fills the field of view at the selected magnification. Whisker length measurements should be made approximately perpendicular to the viewing direction for SEM and optical microscopy.

A.6.7.2 Components with leads

Following the minimum sample sizes as listed in Tables 4 or 5, a minimum of 18 leads shall be inspected. The top, 2 sides, and bends of each identified lead shall be inspected as depicted in Figure A.4. If leads are round then the surface that is the top half of the diameter should be inspected. Whiskers on the two sides may be easier to identify and measure if the component is mounted upside down in the “dead bug” position. For each inspected lead, the maximum whisker length shall be recorded as described in A.6.8. The whisker density shall also be recorded for one lead identified as having the greatest number of whiskers following the protocol outlined in A.6.8.3.3.

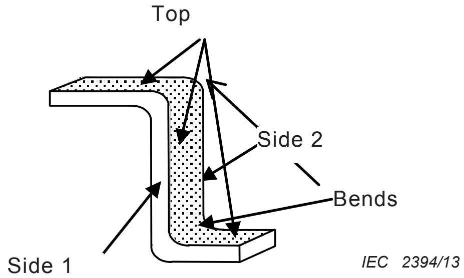


Figure A.4 – A schematic diagram depicting a component lead and the top, 2 sides, and bends of the lead to be inspected

A.6.7.3 Leadless components

The areas to be inspected are denoted by the arrows in Figure A.5

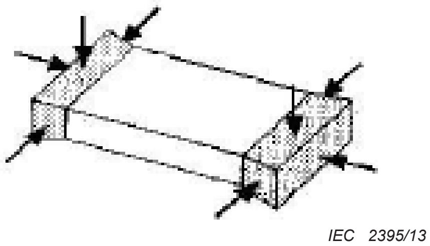


Figure A.5 – A schematic drawing depicting a leadless component and the top and 3 sides of the terminations to be inspected

A.6.7.4 Coupons

A minimum of 9 areas on a minimum of 3 coupons shall be inspected. Each area shall be a minimum of 1,7 mm^2 and should have been identified during the screening inspection. An example of inspection areas is depicted in Figure A.6. For each inspected area, the maximum whisker length shall be recorded as described in A.6.8. The whisker density shall also be recorded for one area identified as having the greatest number of whiskers following the protocol outlined in A.6.8.3.3.

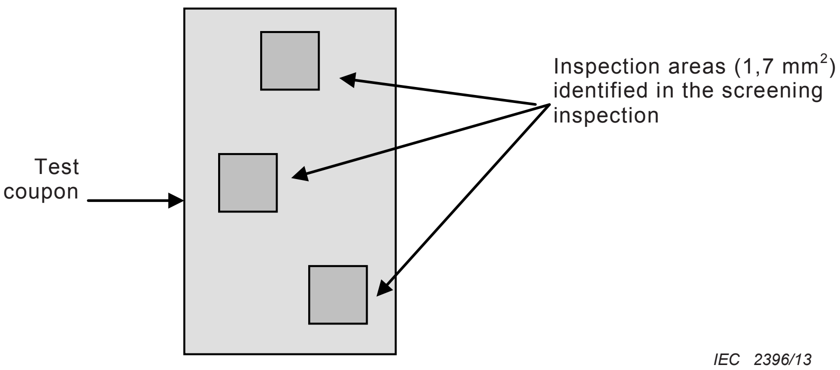


Figure A.6 – A schematic drawing depicting one possible coupon and three 1,7 mm^2 areas identified for inspection

A.6.8 Recording procedure for scientific studies

A.6.8.1 General information

Tin whisker tests standard report formats are shown in Tables A.5 and A.6. The factors listed in Table A.5 are known or believed to influence whisker behaviour. All applicable information should be provided.

Table A.5 – Tin whisker tests standard report formats (general information)

(Add columns as needed)

Basic information:	**Sample ID**	**Sample ID**
Date of inspection		
Test condition		
Cumulative exposure time (hours) or number of cycles at readpoint		
Observations:		
Type of whisker (kinked, straight, branched)		
Length of longest whisker (microns)		
Whisker density (low, medium, high per inspected area)		
Additional comments / exceptions		
Substrate:		
Type (e.g., package, coupon, chip)		
Substrate material (e.g., Cu, CuFe2, alloy 42)		
Forming operation (e.g., etched, stamped)		
Post-finish treatment (none, reflow at temperature, anneal at time and temperature, etc.)		
Time between pre- and post-finish treatment (anneal, reflow, etc.)		
Time between finish application and initiation of environmental aging		
Underplating:		
Underplate date		
Underplate material (e.g., Ni, Ag, etc.)		
Bath type (e.g., sulfamate)		
Underplate type (bright, matte, satin)		
Underplate thickness (microns)		

Tin finish:	Sample ID	Sample ID
Finish application date		
Alloy type (e.g., tin, tin-bismuth)		
If an alloy of tin is used, alloy content range (e.g., 1 % to 3 %)		
Bath type (methane sulfonic acid, mixed acid, etc.)		
Finish type (bright, matte, satin)		
Finish thickness (μm)		
Finish grain size (μm) [a]		
Current density (A/dm)		
Carbon content in the deposit [b]		
Impurity content in the plating bath, Cu[c]		
Impurity content in the plating bath, Zn[c]		
Impurity content in the plating bath, Fe[c]		
Impurity content in the plating bath, Ag[c]		
Impurity content in the plating bath, Pb[c]		
Impurity content in the plating bath, Ni[c]		

[a] Can be measured on the surface of the deposit. The test method should be disclosed.

[b] Carbon content may be measured on a separate coupon sample provided that the plating conditions are similar to the conditions used for creating whisker test samples. The test method should be disclosed.

[c] Impurity content should be measured in the plating bath. These fields are not required, but are recommended to be reported.

A.6.8.2 Recording of screening inspection

For components, the number of components screened per test condition and the number of leads or terminations screened per component shall be recorded. In addition, the number of leads or terminations with whiskers identified shall be recorded. (For example, 6 components and 96 leads were screened and 14 leads exhibited whiskers). For coupons, the number of coupons and the inspection area per coupon that were screened shall be recorded.

A.6.8.3 Recording of detailed inspection

A.6.8.3.1 Items to be recorded

The number of leads, terminations, or inspection areas evaluated in the detailed inspection per test condition shall be recorded. An example format for recording the information is shown in Table A.6. For each lead, termination, or coupon area that is inspected during the detailed inspection, the maximum whisker length shall be recorded. The whisker density shall also be recorded for the one lead, termination, or coupon area exhibiting the greatest number of whiskers.

Table A.6 – Tin whisker tests standard report formats (detailed whisker information)

Screening observations:	**Sample information**	**Features (e.g., corrosion, scratches, clamp marks, etc.)**
Number of samples inspected		
Number of terminations or coupon areas inspected per sample		
Total number of terminations or coupon areas inspected		
Total area inspected		
Number of terminations or coupon areas with whiskers		
Detailed observations:		
Number of samples inspected		
Total number of terminations or coupon areas inspected		
Whisker density (low, medium, high per inspected area)		
Length of longest whisker (μm) – termination or coupon area 1		
Length of longest whisker (μm) – termination or coupon area 2		
Length of longest whisker (μm) – termination or coupon area 3		
Length of longest whisker (μm) – termination or coupon area 4		
Length of longest whisker (μm) – termination or coupon area 5		
Length of longest whisker (μm) – termination or coupon area 6		
Length of longest whisker (μm) – termination or coupon area 7		
Length of longest whisker (μm) – termination or coupon area 8		
Length of longest whisker (μm) – termination or coupon area 9		
Length of longest whisker (μm) – termination or coupon area 10		
Length of longest whisker (μm) – termination or coupon area 11		
Length of longest whisker (μm) – termination or coupon area 12		
Length of longest whisker (μm) – termination or coupon area 13		
Length of longest whisker (μm) – termination or coupon area 14		
Length of longest whisker (μm) – termination or coupon area 15		
Length of longest whisker (μm) – termination or coupon area 16		
Length of longest whisker (μm) – termination or coupon area 17		
Length of longest whisker (μm) – termination or coupon area 18		
Additional comments:		
Additional comments/exceptions:		

A.6.8.3.2 Whisker length

Record the maximum whisker length measured on each lead, termination, or coupon area during the detailed inspection. The whisker length is measured as the straight line distance from the termination/electroplate surface to the most distant point on the whisker (i.e., the radius of a sphere containing the whisker with its centre located at the point of emergence), as depicted in Figure 5.

A.6.8.3.3 Optional for scientific studies: whisker density range

In the screening inspection, one lead or termination for components or one inspection area for coupons shall be identified as having approximately the greatest number of whiskers. For this one lead, termination, or coupon area, a whisker density range shall be determined using the following procedure. For most components, whiskers shall be counted on the entire top and sides of the lead or termination. The number of whiskers shall be recorded along with the amount of surface area that was inspected. Counting may be stopped when the total number of whiskers counted in the inspected surface area exceeds 45 whiskers. The total number of whiskers counted per lead, termination, or coupon area shall be used to classify the whisker density range, according to Table A.7.

NOTE The whisker density range has not been correlated with whisker length. However, the chance of a whisker causing a failure depends on the whisker density. Therefore, reporting of whisker density range can help to improve the understanding of how whisker density correlates (if at all) with maximum whisker length.

Table A.7 – Whisker density ranges that can be determined based on the number of whiskers observed per lead, termination, or coupon area

Maximum whisker density range	Total number of whiskers per lead, termination, or inspected coupon area	Lead, termination, or coupon inspection area
low	$<$ 10 whiskers	(mm^2)
medium	10 to 45 whiskers	(mm^2)
high	$>$ 45 whiskers	(mm^2)

Bibliography

JEDEC/IPC JP002, *Current tin whiskers theory and mitigation practices guideline*

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