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Part 1: Failure mechanisms and measurement methods to evaluate solid insulation for semiconductor devices

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Introduction

This draft standard is based on national and international discussions. Your comments on this draft are invited and will assist in the preparation of the consequent standard.

For international standards, comments will be reviewed by the relevant UK national committee before sending the consensus UK vote and comments to the international committee, which will then decide appropriate action. If the international standard is approved, it is usual for the text to be published as a British Standard.

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Template for comments and secretariat observations

Date: xx/xx/20xx	Document: ISO/DIS xxxx
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1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex (e.g. 3.1)	Paragraph/Figure/ Table/Note	Type of comment	Commend (justification for change) by the MB	Proposed change by the MB	Secretariat observations on each comment submitted
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	



47/2906/CD

COMMITTEE DRAFT (CD)

PROJECT NUMBER: IEC 63492-1 ED1	
DATE OF CIRCULATION: 2025-01-31	CLOSING DATE FOR COMMENTS: 2025-04-25
SUPERSEDES DOCUMENTS: 47/2773/NP, 47/2800A/RVN	

IEC TC 47 : SEMICONDUCTOR DEVICES	
SECRETARIAT: Korea, Republic of	SECRETARY: Mr Cheolung Cha
OF INTEREST TO THE FOLLOWING COMMITTEES: TC 62,TC 66,TC 108,TC 109	HORIZONTAL FUNCTION(S):
ASPECTS CONCERNED: Safety	

This document is still under study and subject to change. It should not be used for reference purposes.

Recipients of this document are invited to submit, with their comments, notification of any relevant patent rights of which they are aware and to provide supporting documentation.

Recipients of this document are invited to submit, with their comments, notification of any local regulations or technical reasons that may exist and should be considered should this proposal proceed, recognizing that failure to address such requirements could result in the need for new or existing "In Some Countries" clauses. (SEE [AC/22/2007](#) OR [NEW GUIDANCE DOC](#)).

TITLE:

Semiconductor devices - Isolation for semiconductor devices - Part 1: Failure mechanisms and measurement methods to evaluate solid insulation for semiconductor devices

NOTE FROM TC/SC OFFICERS:

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

**Semiconductor devices - Isolation for semiconductor devices - Part 1:
Failure mechanisms and measurement methods to evaluate solid
insulation for semiconductor devices –**

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The text of this International Standard is based on the following documents:

Draft	Report on voting
XX/XX/FDIS	XX/XX/RVD

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

The language used for the development of this International Standard is **English** [change language if necessary].

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- reconfirmed,
- withdrawn, or
- revised.

INTRODUCTION

The semiconductor industry has been integrating more and more device functions like sensors, couplers, and other passive and active devices like discrete transformers and capacitances besides their semiconductor chips into one package. Such devices are called “System-in-Package” (SiP).

This has been possible because the semiconductor industry has been investing heavily in the research of new materials, fabrication methods, transistor types, design methods, package technologies, reliability etc.. Therefore, it is not astonishing that based on new materials and fabrication methods now also isolation materials with extraordinary isolation characteristics and robustness are available. Isolation thicknesses of less than 60µm are nowadays possible. Of course, these can be integrated in such SiP configurations. Hence, functions formerly only possible to be realized on large PCBs can now be integrated in standard semiconductor packages. Of course the miniaturization makes the better understanding of the physical effects including breakthrough and ageing mechanisms necessary. Furthermore, methods for the fabrication quality monitoring to detect design flaws and defects have been developed.

For about 20 years the semiconductor industry has shown with their magnetic or capacitance couplers within standard semiconductor packages that thin isolation layers, typical thickness are between 10 and 60µm, can offer the same or even superior isolation performance as isolation with thicknesses above 400µm. Such thin isolation has been used for basic, supplementary, reinforced and double insulation applications as defined by the IEC 60664-1:2020.

The advance in miniaturization requires to provide isolation according to IEC 60664-1:2020EN 60664-3:2017IEC 60664-4:2005 for other functions like current, voltage or temperature sensing.

Hence, the necessity for a horizontal standard on the isolation function within semiconductor devices comes up which not only describes the physical breakdown, ageing and reliability mechanisms, the statistic methods for evaluating the device quality but which also offers a guidance for the set-up of standards on new component standards having an isolation function on the level of the IEC 60664-1:2020.

The above-mentioned targets are realized in this standard. It should be clear that it can just include only that knowledge which was available and verified at the day of its publication.

- The standard can be split-up in the following main topics:
- Summary and literature references on the physical breakdown mechanisms
- Electrical measurement methods and their pros-and-cons
- Statistical methods for Oh-analysis and life-time extrapolation
- Life-time models and their pros-and-cons
- Ageing of the isolation performance
- Procedures for qualifying/certifying the isolation within semiconductor devices

One of the main focuses of this standard are the different ageing mechanisms because they define the life of an electrical insulation system (EIS) or system in package ([electrical insulation SiP](#)). Since an isolation breakdown can end in a fatal fail one has to be very prudent in the development and monitoring of the isolation performance. This can be affected by electrical, thermal, mechanical or environmental stresses acting either individually or in combination. Intended, estimated or proven operation life times are essential parameters for describing the life of electrical insulation systems. In the early days of electrotechnical engineering, life figures were rather vague. The limitation of the life of the insulation under thermal stress was one of the first indicators of the effect of ageing in some equipment in operation. As experience in using EiSiP increased, it was appreciated that there was a need to select specific materials having satisfactory life time at a given temperature, to enable the required operation life to be achieved and to allow for the calculation of the thermal capability of equipment. The user of this standard may evaluate existing test methods and provide correlation with his equipment.

Therefore, the user of this standard is responsible for demonstrating the validity of the existing test method in accordance with the principles of this standard. The determination of the prospective life is a fundamental task when developing and designing an EiSiP. Estimated operation life of an EiSiP needs to be established for several reasons:

- for type testing when introducing a new EiSiP into the market;
- for quality assurance of production;
- for estimating the life expectancy of new products (semiconductor supplier side);
- for estimating the remaining life for maintenance purposes (user side).

“Ageing” focuses on the mechanisms affecting the EiSiP performance. “Evaluation” links these potential mechanisms by “Analysis” and “Diagnostics” to the design of a specific kind of evaluation test procedure. The keyword structure below meets such requirements and allows an easier choice of the parts of interest.

IEC 60505 provides a good overview and base on the important failure mechanisms and aspects related to isolation of equipment. The fundamental failure mechanisms described in the IEC 60505 to a large extent also apply to the field of semiconductors. Hence, in the following document the IEC 60505 was taken as a base and was adapted it to the needs of the field of semiconductors.

Semiconductor devices - Isolation for semiconductor devices - Part 1: Failure mechanisms and measurement methods to evaluate solid insulation for semiconductor devices –

1 Scope

This international standard establishes the basis for evaluating the reliability of solid insulation within a device containing one or more semiconductor components. It shall not be used as stand-alone standard for component certifications, but as reference point for component standards. For device certifications their specific standards shall be used.

It describes the key breakdown mechanisms, ageing behaviour and subsequent failure mechanisms of the isolating semiconductor devices. Further it proposes the measurement methods to address these failure mechanisms of the isolation during development, qualification and production.

Essential insulation material characteristics

- safety tests
- terminology

This international standard specifies the failure mechanisms and measurement methods, essential insulation material characteristics, safety test and terminology for the evaluation of the reliability of solid insulation for semiconductor devices.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60060-1:2010-09, *High-voltage test techniques - Part 1: General definitions and test requirements*

IEC 60068-1, 2013-10:IEC 60068-1, 2013-10, *Environmental testing - Part 1: General and guidance*

IEC 60068-2-1:2007-03, *Environmental testing - Part 2-1: Tests - Test A: Cold*

IEC 60068-2-2:2007-07, *Environmental testing - Part 2-2: Tests - Test B: Dry heat*

IEC 60068-2-6:2007-12, *Environmental testing - Part 2-6: Tests - Test Fc: Vibration (sinusoidal)*

IEC 60068-2-14:2009-01, *Environmental testing - Part 2-14: Tests - Test N: Change of temperature*

IEC 60068-2-17:1994-07, *Basic environmental testing procedures - Part 2-17: Tests - Test Q: Sealing*

IEC 60068-2-20:2008-07, *Environmental testing - Part 2-20: Tests - Test T: Test methods for solderability and resistance to soldering heat of devices with leads*

IEC 60068-2-27:2008-02, *Environmental testing - Part 2-27: Tests - Test Ea and guidance: Shock*

IEC 60068-2-30:2005-08, *Environmental testing - Part 2-30: Tests - Test Db: Damp heat, cyclic (12 h + 12 h cycle)*

IEC 60068-2-58:2015-03, *Environmental testing - Part 2-58: Tests - Test Td: Test methods for solderability, resistance to dissolution of metallization and to soldering heat of surface mounting devices (SMD)*

IEC 60068-2-67:1995-12, *Environmental testing - Part 2: Tests - Test Cy: Damp heat, steady state, accelerated test primarily intended for components*

IEC 60112:2009-10, *Method for the determination of the proof and the comparative tracking indices of solid insulating materials*

IEC 60112:2003, *Method for the determination of the proof and the comparative tracking indices of solid insulating materials* urn:iec:std:iec:60112:2003-01::||amd:1:2009-08IEC 60112:2003/AMD1:2009

IEC 60216-1:2013, *Electrical insulating materials - Thermal endurance properties - Part 1: Ageing procedures and evaluation of test results*

IEC 60216-1:2013-03, *Electrical insulating materials - Thermal endurance properties - Part 1: Ageing procedures and evaluation of test results*

IEC 60216-2, *Electrical insulating materials - Thermal endurance properties - Part 2: Determination of thermal endurance properties of electrical insulating materials - Choice of test criteria*

IEC 60216-2:2005-08, *Electrical insulating materials - Thermal endurance properties - Part 2: Determination of thermal endurance properties of electrical insulating materials - Choice of test criteria*

IEC 60216-3, *Electrical insulating materials - Thermal endurance properties - Part 3: Instructions for calculating thermal endurance characteristics*

IEC 60216-5, *Electrical insulating materials - Thermal endurance properties - Part 5: Determination of relative thermal endurance index (RTE) of an insulating material*

IEC 60270: 2000-12, *High-voltage test techniques - Partial discharge measurements*

IEC 60493-1, *Guide for the statistical analysis of ageing test data - Part 1: Methods based on mean values of normally distributed test results*

IEC 60505, *Evaluation and qualification of electrical insulation systems*

IEC 60505:2011, *Evaluation and qualification of electrical insulation systems*

IEC 60544-1, *Electrical insulating materials - Determination of the effects of ionizing radiation - Part 1: Radiation interaction and dosimetry*

IEC 60664-1:2020, *Insulation coordination for equipment within low-voltage supply systems - Part 1: Principles, requirements and tests*

IEC 60664-1:2007-04, ed2 *Insulation coordination for equipment within low-voltage systems - Part 1: Principles, requirements and tests*

IEC TR 60664-2-2:2002, *Insulation coordination for equipment within low-voltage systems - Part 2-2: Interface considerations - Application guide*

IEC 60664-4:2005, *Insulation coordination for equipment within low-voltage systems - Part 4: Consideration of high-frequency voltage stress*

IEC 60672-2:1999-12, *Ceramic and glass insulating materials - Part 2: Methods of test*

IEC 60695-11-5:2004-12, *Fire hazard testing - Part 11-5: Test flames - Needle-flame test method - Apparatus, confirmatory test arrangement and guidance*

IEC 60747-5-5, *Semiconductor devices - Part 5-5: Optoelectronic devices - Photocouplers*

IEC 60747-17, *Semiconductor devices - Part 17: Magnetic and capacitive coupler for basic and reinforced insulation*

IEC 61000-4-5:2005-11, *Electromagnetic compatibility (EMC) - Part 4-5: Testing and measurement techniques - Surge immunity test*

IEC 61000-4-8:2009-09, *Electromagnetic compatibility (EMC) - Part 4-8: Testing and measurement techniques - Power frequency magnetic field immunity test*

IEC 61000-4-9:2001-03, *Electromagnetic compatibility (EMC) - Part 4-9: Testing and measurement techniques - Pulse magnetic field immunity test*

IEC/TS 61251, *Electrical insulating materials - AC voltage endurance evaluation - Introduction*

IEC 61251:2015, *Electrical insulating materials and systems - AC voltage endurance evaluation*

IEC 61649:2008, *Weibull analysis*

IEC 61649:2008, *Weibull analysis*

IEC 62368-1:2014-02, *Audio/video, information and communication technology equipment - Part 1: Safety requirements*

IEC 62368-1:2023, *Audio/video, information and communication technology equipment - Part 1: Safety requirements*

IEC 62539:2007-07, *Guide for the statistical analysis of electrical insulation breakdown data*

IEC 62539, *Guide for the statistical analysis of electrical insulation breakdown data*

EN 60664-3:2017, *Insulation coordination for equipment within low-voltage systems - Part 3: Use of coating, potting or moulding for protection against pollution*

EN 61251:2016, *Electrical insulating materials and systems - A.C. voltage endurance evaluation*

EN IEC 62368-1:2024, *Audio/video, information and communication technology equipment - Part 1: Safety requirements*

ECPE Guideline AQG324: Qualification of Power Modules for Use in Power Electronics Converter Units in Motor Vehicles, May 2021

3 Terms and definitions

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

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at <https://www.electropedia.org/>
- ISO Online browsing platform: available at <https://www.iso.org/obp>

3.1 General Terms

3.1.1

system in a package

SiP

Device containing a number of integrated circuits (IC), discrete devices like resistors, inductors, varistors, etc. encapsulated in one package. The SiP can fulfil logic, analog, power, sensor, isolation, etc. functions.

3.1.2**electrical insulation SiP
EiSiP**

SiP containing one or more electrical insulating materials (**EIM**) together with associated conducting parts like ICs, resistors, inductors, capacitances, etc.. Besides its logic, analogue, sensing, and power functions there is also an isolation function, which means that the EiSiP separates the conducting parts at different electrical potentials during operation.

3.1.3**electrical insulating material
EIM**

material with negligibly low electric conductivity, used to separate conducting parts at different electrical potentials

3.1.4**solid insulation**

solid insulating material or a combination of solid insulating materials, placed between two conductive parts or between a conductive part and a body part

3.1.5**multilayer insulation**

A stack of insulating materials (either same or different). Can be fabricated in different deposition steps or different materials laminated or attached on each other.

3.1.6**cemented joint**

Joint between two insulation material parts connecting them in a way that they can be considered as being a single part in regard to insulation over lifetime.

3.1.7**functional insulation**

insulation between conductive parts which is necessary only for the proper functioning of the equipment

Note 1 to entry: The requirements for this insulation type is defined by the supplier. Nevertheless, clearance and creepage are defined by the IEC 60664-1:2020.

3.1.8**basic insulation**

insulation of hazardous-live-parts which provides basic protection

Note 1 to entry: This concept does not apply to insulation used exclusively for functional purposes.

3.1.9**supplementary insulation**

independent insulation applied in addition to basic insulation for fault protection

[SOURCE: IEC 60050-826:2004, 826-12-15]

3.1.10**double insulation**

insulation comprising both basic insulation and supplementary insulation

3.1.11**reinforced insulation**

insulation of hazardous-live-parts which provides a degree of protection against electric shock equivalent to double insulation

Note 1 to entry: Reinforced insulation may comprise several layers which cannot be tested singly as basic insulation or supplementary insulation.

3.2 Terms related to stresses and ageing

3.2.1

estimated life

expected life derived from the results of tests performed in accordance with appropriate evaluation procedures, or both, as established by the responsible organization or technical committee.

3.2.2

ageing stress

electrical, thermal, mechanical or environmental stress whose action on an EiSiP causes irreversible property changes

3.2.3

potentially destructive stress

stress in operation which can cause the failure of the aged EiSiP, alone or in combination with other stresses

3.2.4

ageing

irreversible changes of the properties of an EiSiP due to action by one or more stresses

Note 1 to entry: Some changes (e.g. hydrolytic changes) can be partly reversible if the ambient conditions change.

Note 2 to entry: Ageing leads to degradation of the EiSiP.

3.2.5

intrinsic ageing

irreversible changes of fundamental properties of an EiSiP caused by the action of ageing factors on the EiSiP

3.2.6

extrinsic ageing

irreversible changes of properties of an EiSiP caused by action of ageing factors on unintentionally introduced imperfections in the EiSiP

3.2.7

interaction

modifications of the type or degree of ageing produced by the combination of two or more stresses relative to their ageing effect if acting individually on separate objects

3.2.8

direct interaction

interaction between simultaneously applied stresses that differs from that occurring with sequentially applied stresses

3.2.9

indirect interaction

interaction which occurs between simultaneously applied stresses, which remains unchanged when the factors are applied sequentially

3.2.10

storage temperature

T_{stg}

temperature in non-operation condition

Note 1 to entry: Normally for plastic packaged parts one differentiates between Grade 0 (+175°C T_a for 1000 hours or +150°C T_a for 2000 hours), Grade 1 (+150°C T_a for 1000h or +175°C T_a for 500 hours) and grades 2 and 3 (+125°C T_a for 1000 hours or +150°C of +150°C T_a for 500 hours). (AEC-Q100)

Note 2 to entry: Typically for ceramic packaged parts +250°C T_a for 10 hours or +200°C T_a for 72 hours are specified.

3.2.11**ambient temperature** **T_a**

ambient temperature is the air temperature of any object or environment where equipment is stored or operated.

3.2.12**virtual junction temperature** **T_{vj}**

virtual junction temperature is the temperature of a semiconductor die measured by means of thermally sensitive electric parameters (TSEP). This temperature is used for rating semiconductors. A maximum value is given in the datasheet. As virtual junction temperature represents a weighted spatial average, local temperatures can be significantly higher, especially on larger power semiconductor dies, short for transistor junction temperature, is the highest operating temperature of the actual semiconductor in an electronic device. In operation, it is higher than case temperature and the temperature of the part's exterior. The difference is equal to the amount of heat transferred from the junction to case multiplied by the junction-to-case thermal resistance the die dissipates its losses through the package and parts of the package not being in close proximity of the die will operate at lower temperature.

3.2.13**electrical insulation material temperature** **T_{EIM}**

maximum temperature of the electrical insulation material under normal operation conditions at a location where it has to provide insulation within the scope of this standard.

3.2.14**operating temperature** **T_{OP}**

an operating temperature is the allowable temperature range of the local ambient environment at which an electrical or mechanical device operates. The device will operate effectively within a specified temperature range which varies based on the device function and application context.

3.2.15**maximum continuous input power** **P_{SI}**

maximum continuous input power at ambient or a reference point temperature of 25°C and derating curve or derating factor

3.2.16**maximum output current** **I_{SO}**

current used for power dissipation considerations to determine safety limitation

3.2.17**maximum output power dissipation** **P_{SO}**

maximum output power dissipation of the output stage at ambient or a reference point temperature of 25°C and derating curve or derating factor

3.2.18**maximum power transmission** **P_{TR}**

power transferred across isolation barrier during operation

3.2.19**maximum ambient safety temperature****T_s**

highest ambient temperature permitted in the event of a fault

3.2.20**storage modulus****E**

The storage modulus is a viscoelastic property representing the elastic portion of tensile deformation

3.3 Terms related to testing**3.3.1****functional test**

procedure to obtain information about the suitability of an EISIP under specified conditions

3.3.2**test object**

sample of original equipment or part thereof, or model representing the equipment completely or partially, including the EISIP, to be used in a functional test

3.3.3**accelerated ageing**

ageing resulting of an increase in the level and/or frequency of application of the stress beyond normal operation conditions

3.3.4**accelerated test**

functional test applying accelerated ageing to shorten testing time

3.3.5**conditioning**

subjecting a specimen to an atmosphere of a specified relative humidity or complete immersion in water or other liquid, at a specified temperature for a specified period of time

3.3.6**pre-diagnostic conditioning**

variable or fixed stresses, which can be applied continuously or periodically to an EISIP to enhance the ability of a functional test to detect the degree of ageing

Note 1 to entry: Pre-diagnostic conditioning may cause additional ageing.

3.3.7**diagnostic factor**

variable or fixed stress which is applied to an EISIP to establish the degree of ageing

3.3.8**diagnostic test**

periodic or continuous application of a specified level of a diagnostic factor to a test object to determine whether or when the end-point criterion has been reached

3.3.9**end-point criterion**

moment when a system is no longer able to fulfil its operation purposes

3.3.10**life time**

for a property to reach the end-point criterion for objects in functional tests

3.3.11**test cycle**

in a test, repetitive period of application of one or more stresses, either sequentially or simultaneously, and of diagnostic factors

3.3.12**sub-cycle**

defined period within test cycle

Note 1 to entry: The subcycle may be, for instance, a period of application of high temperature and humidity for influencing the system properties, or application of high voltage for diagnostic purposes

3.3.13**type test**

test made on one or more devices representative to a certain design to check the conformity to the specifications of a new EISiP product.

Note 1 to entry: In the language of the semiconductor industry the type test is the qualification test.

3.3.14**routine test**

conformity test made on each individual item during or after manufacture.

Note 1 to entry: In the semiconductor industry this is called production test.

[SOURCE: IEC 60050-151:2001, 151-16-17]

3.3.15**sampling test**

test on a number of devices taken at random from a batch.

Note 1 to entry: In the semiconductor industry it is called monitoring and can be performed on monthly, quarterly or yearly base.

3.3.16**partial discharge****PD**

electric discharge that partially bridges the insulation

Note 1 to entry: A partial discharge may occur inside the insulation or adjacent to a conductor.

Note 2 to entry: Scintillations of low energy on the surface of insulating materials are often described as partial discharges but should rather be considered as disruptive discharges of low energy, since they are the result of local dielectric breakdowns of high ionization density, or small arcs, according to the conventions of physics.

[SOURCE: IEC 60050-442:2014, 442-09-05, modified - Notes 1 and 2 to entry have been added.]

3.3.17**partial discharge inception voltage**

lowest peak value of the test voltage at which the apparent charge becomes greater than the specified discharge magnitude when the test voltage is increased above a low value for which no discharge occurs

Note 1 to entry: is used to characterize [partial discharge](#)

3.3.18**partial discharge extinction voltage**

lowest peak value of the test voltage at which the apparent charge becomes less than the specified discharge magnitude when the test voltage is reduced below a high level where such discharges have occurred

Note 1 to entry: is used to characterize [partial discharge](#)

3.3.19**partial discharge test voltage**

peak value of the voltage in a [partial discharge](#) test, where the apparent charge is less than the specified discharge magnitude

Note 1 to entry: defines the partial discharge test voltage

Note 2 to entry: at this voltage the measured partial discharge should be below a scrap or fail limit

3.4 Terms related to field application stress

3.4.1

clearance

shortest distance in air between two conductive parts

3.4.2

creepage distance

shortest distance along the surface of a solid insulating material between two conductive parts

[SOURCE: IEC 60050-151:2001, 151-15-50]

3.4.3

working voltage

VIOWM

highest RMS value of the AC or DC voltage across any particular insulation which can occur when the equipment is supplied at rated voltage

Note 1 to entry: Transient overvoltage is disregarded.

Note 2 to entry: Both open-circuit conditions and normal operating conditions are considered.

[SOURCE: IEC 60664-1:2020]

3.4.4

steady-state working voltage

working voltage after the transient overvoltage phenomena have subsided and not considering short-term voltage variations

[SOURCE: IEC 60664-1:2020]

3.4.5

steady-state peak

voltage peak value of the steady-state working voltage

Note 1 to entry: In case of pulse-width modulation (PWM) the steady state peak voltage shows up at every switching period.

[SOURCE: IEC 60664-1:2020]

3.4.6

recurring peak voltage

VIORM

Recurring peak voltage (repetitive peak isolation) voltage assigned by the manufacturer of the device, characterizing the specified withstand capability of its isolation against repetitive peak voltages (recurring peak voltages).

Note 1 to entry: Random overvoltages, for example due to occasional switching, are not considered to be recurring peak voltages.

Note 2 to entry: Long-term temporary overvoltage should be taken in considerations.

[SOURCE: IEC 60664-1:2020]

3.4.7

overvoltage

any voltage having a peak value exceeding the corresponding peak value of maximum steady-state working voltage at normal operating conditions

3.4.8

temporary overvoltage

overvoltage at power frequency of relatively long duration

Note 1 to entry: The IEC 60664-1 distinguishes between short-term (> 5sec) and long-term temporary overvoltage.

3.4.9**transient overvoltage****VIOTM**

peak isolation voltage which includes all non-repetitive transient voltages like short-term, long-term temporary overvoltage, maximum impulse voltage and applies to the package clearance as well as internal insulation

Note 1 to entry: See IEC 60664-1:2007.

3.4.10**withstand voltage****VISO**

voltage to be applied to a specimen under specified test conditions which does not cause breakdown of insulation and/or flashover of a satisfactory specimen

3.4.11**impulse withstand voltage****VIMP**

highest peak value of impulse voltage of specified form and polarity which does not cause breakdown of insulation or flash-over under specified conditions

3.4.12**surge isolation voltage****VIOSM**

highest instantaneous value of an isolation voltage pulse with short time duration and of specified wave form (1,2/50 μ s) applied across the internal insulation of the device

Note 1 to entry: The IEC 61000-4-5 describes the 1,2/50 μ s pulse caused by switching and lightning transients

Note 2 to entry: Testing of required VIOSM may be conducted for example in oil to exclude arcing/flashover across the surface or in air

3.4.13**temporary withstand overvoltage**

highest RMS value of a temporary overvoltage which does not cause breakdown of insulation under specified conditions

4 Insulation Materials**4.1 Solid Insulation**

Solid insulation materials play a crucial role in [electrical insulation SiP](#). They are used in the design to resist electrical stresses and to prevent short circuits and electrical shocks, thus ensuring their functionality and safety. Common solid insulation materials include organics and inorganics. For IC manufacturing SiO₂ (glass), SiN, SiON, polymers, composite materials, imides, and other materials are employed for their excellent electrical and dielectric properties.

In packaging, molding compounds (epoxy resin filled with inorganic particles), silicon gels and imides are chosen for their high dielectric strength, but also their resistance to heat and flames. Other materials, such as ceramics are used for their high temperature stability.

The choice of insulation material is critical in this context, as it impacts the efficiency and safety of the [electrical insulation SiP](#).

Despite their numerous benefits, solid insulation materials also come with some challenges. These include issues with thermal management, mechanical stresses, and compatibility with other materials. Therefore, it is of high importance to select insulation materials that not only meet the immediate needs of the application but also offer superior long-term performance. This contributes to the safety, cost-effectiveness, efficiency, and overall reliability of electrical and electronic systems.

Solid insulation materials are chosen for specific purposes based on their unique properties. Here are some typical properties that are often considered:

Dielectric Strength: This refers to a material's ability to withstand electrical stress without breaking down. High dielectric strength prevents electrical failure.

Electrical Resistivity: This is the ability of a material to resist the flow of electric current. High resistivity is preferable as it ensures that the material does not conduct electricity and can effectively insulate electrical components.

Thermal Stability: Solid insulation materials should be able to resist high temperatures and maintain their insulating properties under thermal stress.

Flame Retardancy: This property signifies the material's resistance to catching fire. This is important for safety purposes.

Mechanical Strength: Solid insulators should be robust enough to withstand the mechanical stress they will face in their intended applications.

Chemical Resistance: Solid insulation materials should be resistant to chemicals, moisture, and other environmental factors that could degrade their insulating properties over time.

Low Water Absorption: Materials with low water absorption are less likely to degrade due to moisture, prolonging their lifespan and effectiveness.

Structural Properties: In some applications, solid insulators also serve as structural components and therefore need to possess certain physical properties, such as rigidity or flexibility, depending on the application.

Compatibility: The material should be compatible with the other materials used in the system, meaning it should not react chemically or physically in a detrimental way.

Cost-Effectiveness: Although not a physical property, the cost-effectiveness of a material is a crucial factor considered in its selection.

It's important to note that not all solid insulators will possess all these properties, and the selection of a specific material will depend on the precise requirements of the application.

Also note, that long term insulation performance not only depend on the intrinsic material properties, but on the quality achieved during the manufacturing process. For example, voids created by injection molding or adhesive dispensing can serve as source for [partial discharge](#).

4.2 Multilayer Insulation

[multilayer insulation](#) stacks establish an electrical barrier and ensure mechanical strength. They can also decrease the probability of breakdown at material pinholes. Multilayer materials can e.g. be made of different thin films (e.g. of several μm to tens of micron) – typical for packaging – or out of one material processed in several steps which is often used in chip technology.

The incorporation of various materials in a multilayer system allows for a balanced set of properties that a single material may not provide. For instance, one layer might offer high electrical insulation like a polyimide sheet while another ensures mechanical stability like an adhesive layer. One of the core advantages of multilayer insulation stacks is their space efficiency. They deliver high insulation properties in a compact, thin format, which is particularly beneficial in applications where space is at a premium. Additionally, these structures can aid in thermal management. Certain layers can be designed to dissipate heat away from crucial components, thereby averting overheating. Multilayer insulation is indispensable in high voltage applications, where it can inhibit electrical breakdown by distributing the electric field across several layers, each bearing a lower breakdown voltage. Moreover, the design of multilayer stacks can be customized to meet specific application requirements by adjusting the combinations of materials, the thickness of layers, and the overall configuration of the stack. Nevertheless, the design and manufacture of multilayer insulation stacks necessitate attention. The materials employed must be compatible to avoid chemical reactions or differential thermal expansion, which could result in premature failure. Even minor flaws, like air bubbles or uneven layers, can noticeably degrade the insulating properties of the stack. As such, the production process needs to adhere to high standards of quality control to ensure the integrity and performance of the multilayer insulation stack. Furthermore, appropriate in-line and product tests like partial discharge and high-voltage stress tests are needed.

4.3 Material Interfaces

Multilayer insulations are helpful on one hand but on the other hand all material interfaces result in dangling bonds/shallow traps and possible delamination risks due to thermo-mechanical stress. The thermo-mechanical stress results out of the different thermal expansion coefficients of the materials (CTE). One has to keep in mind that the mechanical stress can be in the range of GPa. The delamination results in voids leading to increased [partial discharge](#) degradation. Voids can also be filled with moisture which results in further delamination or even in water treeing. Most problematic material interfaces are the so called [cemented joint](#) (EN IEC 62368-1:2024/IEC 62368-1:2023) which are interfaces connecting the electrodes (see [Figure 1](#)). This figure shows a typical opto-coupler construction.

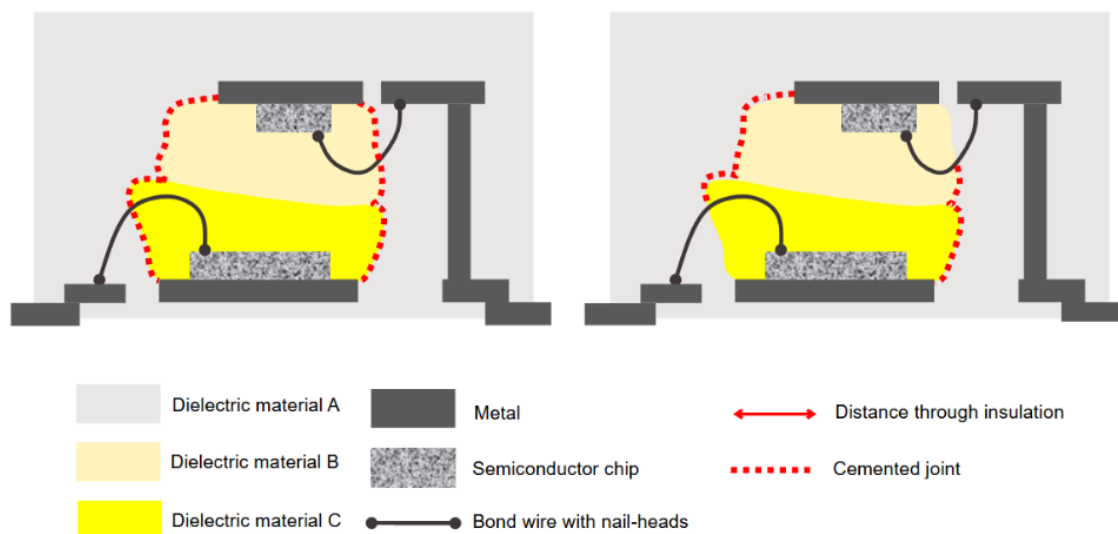


Figure 1 – This figure shows the different cemented joints taking also the bond-wires in consideration.

Along these interfaces the shallow traps function as hopping centers for electrons (Frenkel-Poole). [cemented joint](#) have definitely a higher conductivity as the surrounding bulk material. These joints starting or ending at bond-wires or edges are absolutely problematic because at these locations the electron injection via Fowler Nordheim tunneling occurs even at low E -fields.

In many standards a minimum distance through insulation (DTI) of 400µm is required. The [Figure 2](#) shows several DTIs. Semiconductor materials should be considered as conductive materials for the DTI analysis. It is absolute important to note that all edges and bond-wires are problematic due to electron injection via Fowler-Nordheim tunnel.

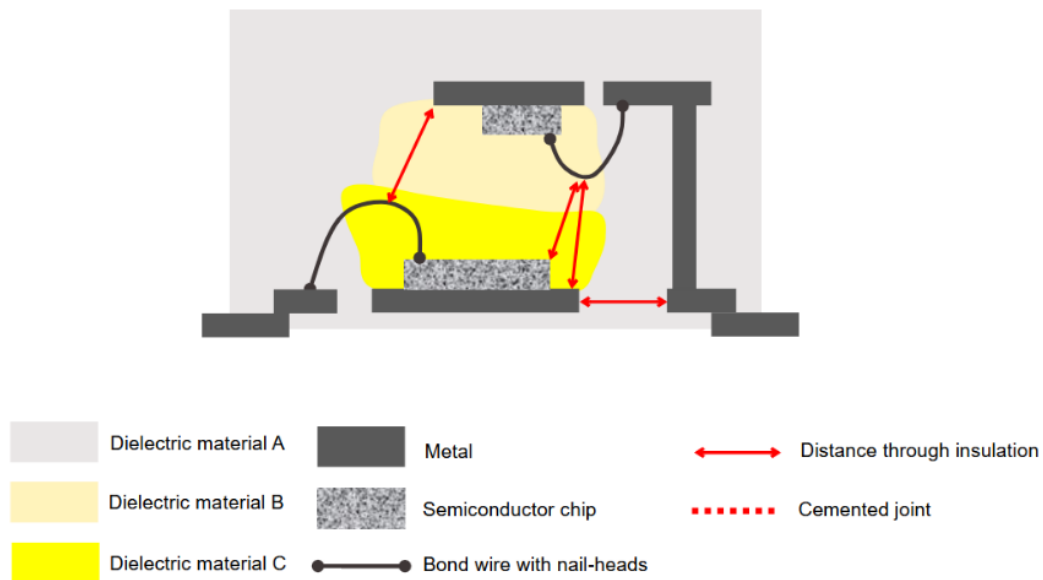


Figure 2 – The minimum distance through insulation (DTI) has to be determined. Several distances are shown. The smallest one is the decisive one. Semiconductor regions are considered to be conductive as metals for this analysis.

Because all interfaces are conductive one has to be cautious respective the DTI analysis as the following [Figure 3](#) shows. Although the construction fulfills the 400µm requirement, the red indicated breakdown path along the polymer interface takes place by a probability of 50%. Hence, the [cemented joint](#) and DTI-rule is questionable.

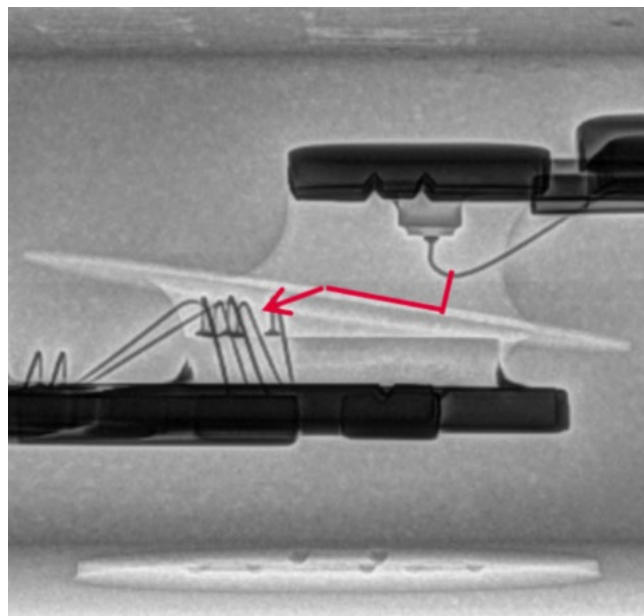


Figure 3 – The red line indicates a potential breakdown path, partly along the polymer interface.

Another problem arises out of the traps filled with electrons. These electrons can be detrapped and will then move around building up space charges, detrapping further electrons, breaking