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Space systems — Thermal control coatings for spacecraft — Atomic oxygen protective coatings on polyimide film

Systèmes spatiaux — Revêtements de contrôle thermique pour engins spatiaux — Revêtements de protection contre l'oxygène atomique sur film polyimide

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Contents

Page

Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document describes technical information for the selection and application of atomic oxygen protective coatings as required to confirm conformity with the requirements for the protection of polyimide film.

Satellites in low Earth orbit are bombarded by high-energy radiation particles and gas particles such as atomic oxygen (AO). In particular, AO corrodes certain materials, thereby weakening a spacecraft's exterior and potentially damaging its instruments. Polymers are significantly eroded.

Polyimide films are widely used as multilayer insulation materials on a spacecraft's exterior, which is exposed directly to the space environment. Despite these interesting properties, polyimide shows poor resistance to AO. Therefore, polyimide is often coated with an additional protective coating for resistance to AO. Such films have unique characteristics that are relevant for different applications. This document summarizes the coating properties, as well as a comparison or consideration of the pros and cons for selection.

This document provides a property map of the types of AO protective coatings available to spacecraft designers and thermal control film manufacturers. It enhances coating selection, indicates selection guidelines, and improves the reliability of spacecraft.

Requirements for coating properties and quality control are also defined, so as to eliminate defective products, improve the quality and function of films, accelerate the exchange and distribution of coating techniques, invite new providers to the market, introduce competition, and enhance international trade.

Space systems — Thermal control coatings for spacecraft — Atomic oxygen protective coatings on polyimide film

1 Scope

This document defines the general requirements for atomic oxygen (AO) protective coatings that are applied on polyimide thermal control films. It also describes the different properties of coated polyimide films such as indium tin oxide (ITO), SiO_x, germanium, and silicone, property measurement test methods, and selection guidelines.

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.

ISO 16378, *Space systems — Measurements of thermo-optical properties of thermal control materials*

ISO 27025:2010, *Space systems — Programme management — Quality assurance requirements*

ASTM D257, *Standard Test Methods for DC Resistance or Conductance of Insulating Materials*

ASTM E595, *Standard Test Method for Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment*

ASTM E1559, *Standard Test Method for Contamination Outgassing Characteristics of Spacecraft Materials*

ECSS-ST-Q70-02, Thermal vacuum outgassing test for the screening of space materials

3 Terms, definitions and abbreviated terms

3.1 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:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1.1
atomic oxygen
oxygen molecules separated by ultraviolet light from the sun, which are main atmospheric constituents in the range of about 200 km to 700 km

Note 1 to entry: As a spacecraft orbits the Earth at high speed, atomic oxygen can collide with the spacecraft's surface at high speed and degrade the surface material.

3.1.2
coating
continuous layer formed from a single or multiple application of a *coating material* (3.1.3) to a *substrate* (3.1.8)

[SOURCE: ISO 4618:2014, 2.50.1, modified — "continuous" has been added at the beginning.]

3.1.3
coating material
product, in liquid, paste or powder form, that, when applied to a *substrate* (3.1.8), forms a film possessing protective and/or other specific properties

Note 1 to entry: Coating materials are often applied using a chemical or plasma vapour deposition process from solid source materials. General types of AO protective *coatings* (3.1.2) are listed in Annex A.

[SOURCE: ISO 4618:2014, 2.51, modified — "layer" has been replaced by "film"; "decorative" after "protective" has been removed; the original note 1 to entry has been removed and replaced by a new one.]

3.1.4
coating process
process of applying a *coating material* (3.1.3) to a *substrate* (3.1.8), such as dipping, spraying, roller *coating* (3.1.2), and brushing

Note 1 to entry: A chemical or plasma vapour deposition process is also commonly applied.

3.1.5
emittance
emissivity
ε
$\varepsilon = M/M_b$
where

M is the radiant exitance of a thermal radiator;

M_b is the radiant exitance of a blackbody at the same temperature

Note 1 to entry: The following adjectives should be added to define the conditions (see ISO 9288):

— total: when related to the entire spectrum of thermal radiation (this designation can be considered as implicit);

— spectral or monochromatic: when related to a spectral interval centred on wavelength λ;

— hemispherical: when related to all directions along which a surface element can emit or receive radiation.

— directional: when related to the directions of propagation defined by a solid angle around the defined direction;

— normal: when related to the normal direction of propagation or incidence to the surface.

Note 2 to entry: See ISO 80000-7: 2019, item 7-30.1.

3.1.6
polyimide
generic name of a polymer that contains imide monomers

3.1.7
solar absorptance
α_s
ratio of the solar radiant flux absorbed by a material (or body) to the radiant flux of the incident radiation

[SOURCE: ISO 16378:2013, 3.12, modified — Note 1 to entry has been removed.]

3.1.8
substrate
surface to which a *coating material* (3.1.3) is applied or is to be applied

[SOURCE: ISO 16691:2014, 3.1.14]

3.1.9
witness sample
sample pieces that represent the coated product

Note 1 to entry: These samples are made in the form of flat plates using the same *coating material* (3.1.3) as used with the product, and then coated simultaneously. They are used for destructive tests and testing that requires a limited specimen size.

[SOURCE: ISO 16691:2014, 3.1.17, modified — Note 1 to entry has been updated editorially.]

3.2 Abbreviated terms

This document uses the following abbreviated terms:

AO	atomic oxygen
CVCM	collected volatile condensable materials
CVD	chemical vapor deposition
EB	electron beam
EMI	electromagnetic interference
EOL	end-of-life
ESH	equivalent solar hours
ITO	indium tin oxide
LEO	low Earth orbit
MLI	multi layer insulation
RF	radio frequency
RML	recovered mass loss
TML	total mass loss
UV	ultraviolet
VUV	vacuum ultraviolet

4 General requirements and recommendations

4.1 General

This clause defines the requirements and recommendations regarding the fundamental properties of coated film. The related data and test methods are provided to the customer for spacecraft design. Table 1 lists the general test provisions.

Table 1 — Overview of general test provisions

Tests	Requirement	Recommendation
Visual characteristics	X	
Coating thickness	X	
Thermo-optical properties	X	

Table 1 *(continued)*

Tests	Requirement	Recommendation
Thermal vacuum stability	X	
AO resistance	X	
UV resistance		X
Radiation resistance		X
Adhesion		X
Volume resistance		X
Surface resistance	X	
Secondary electron emission yield		X
Photoelectron emission yield		X
Thermal cycling		X

4.2 Visual characteristics

The coated film as received by the customer shall be smooth, continuous, free from delamination within the coating, uniform in appearance, and free from imperfections detrimental to usage of the coated film. Coated film shall be visually free from scratches, cracks, separation and any unallowable discoloration. Annex D provides the guideline to a visual inspection.

4.3 Coating thickness

The coating thickness range shall be provided. The thickness of AO protective coating shall be within the allowable range defined in the product specifications. Excessive thickness would cause cracks and/or separation.

Base film with perforations is more vulnerable due to coating failure around the holes. Coating shall be applied on the section edge of a perforation to prevent AO erosion. Annex B lists the typical values of the general coating thickness of AO protective coatings.

4.4 Thermo-optical properties

The thermo-optical properties of coated film shall be submitted. Annex B lists the typical values of the general properties of AO protective coatings.

AO, UV, and energetic particles can cause changes in thermo-optical properties. Any changes in the thermo-optical properties of coated film shall be measured when requested by project. AO protection coating shall not increase the magnitude of a change in base film properties.

4.5 Thermal vacuum stability

Effused gas from coated film under a vacuum condition shall be low. Annex B lists the typical values of the general properties of AO protective coatings.

4.6 AO resistance

AO protective coating shall guard its base film up to a spacecraft's EOL without any openings penetrating the coating layer. Erosion of the base film due to cracks, separation, degradation and erosion of AO protective coating shall not occur. Annex B lists the typical mass loss values after AO irradiation.

4.7 UV resistance

Coated film applied to the outer surface of a spacecraft is subject to strong UV rays. Thermo-optical properties are degraded by UV. The thermo-optical properties of AO protective coating should be maintained within the allowable range. Annex B lists the typical thermo-optical properties after UV irradiation.

4.8 Radiation resistance

Coated film is subject to protons and electrons. Thermo-optical properties are degraded by radiation. The thermo-optical properties of AO protective coating should be maintained within the allowable range. Annex B lists the typical thermo-optical properties after radiation exposure.

4.9 Adhesion

AO protection coating should have no peeling after the tape stripping test as defined in Clause 5.

4.10 Volume resistance

AO protective coating should not increase volume resistance of the base film.

Coated film that can have an adverse effect on spacecraft systems and hardware due to their electrical characteristics and properties shall be reviewed by EMI engineering for conformity with program specifications, and specifically approved for use on the program.

4.11 Surface resistance

Surface resistance data shall be provided to the customer. Annex B lists the surface resistance values of typical coated films.

Coated film that can have an adverse effect on spacecraft systems and hardware due to their electrical characteristics and properties shall be reviewed by EMI engineering for conformity with program specifications, and specifically approved for use on the program.

4.12 Secondary electron emission yield

Secondary electron emission yield data should be provided to the customer when requested.

4.13 Photoelectron emission yield

Secondary electron emission yield data should be provided to the customer when requested.

4.14 Thermal cycling

Coated film should function in the temperature range of -190 °C to +200 °C, unless otherwise stated in the standard for each coated film.

4.15 Repair/Retouch

When the coated film is repairable, the coating supplier shall provide the repair/retouch procedure.

4.16 Cleaning

Coated film shall be easy for cleaning. The coating supplier shall provide the cleaning procedure, including compatible cleaning agent and prohibited chemicals.

5 Test methods

5.1 General

Both reliability and quality are confirmed by testing in the production of AO protective coatings to be applied on polyimide thermal control films.

In addition, the effects of the space environment largely depend on the spacecraft service conditions, which are defined by the orbits where spacecraft are intended to operate. Especially for LEO spacecraft, AO attacks and erodes the surface material of spacecraft. And there are also general factors that affect spacecraft serviceability and efficiency, such as a vacuum, electromagnetic solar radiation (including UV and VUV radiation), ionizing radiation, temperature, and the effects of a contaminated environment. Therefore, such undesirable effects as electrostatic charging, generating a spacecraft outer atmosphere, and alternating thermal loads can occur during operation.

5.2 Visual inspection

Coated film shall be subject to visual inspection with the naked eye and/or electronic magnification. Witness samples approved by the manufacturer shall be used for any required comparison. The samples shall be prepared from the materials and processes that are used in spacecraft.

The product is considered acceptable when there are no harmful disadvantages in its use. Annex D provides the guideline to a visual inspection.

5.3 Coating thickness

The thickness of coated film or the coating itself shall be controlled in the product process. Data on coating thickness and its measurement method shall be provided to the customer when requested.

5.4 Thermo-optical properties

a) The thermo-optical properties shall be measured before and after space environment resistance tests.

b) Measurements shall be performed on the samples according to ISO 16378. Another measurement method may be applied with the customer's approval. The measurement method shall be recorded and reported.

c) The samples used for the measurement of thermo-optical properties shall be of the same batch/lot as that of the flight material.

d) The thermo-optical properties at EOL are estimated by testing and analysis. The measurements and analysis of $\Delta\alpha_s$ and $\Delta\varepsilon$ of the coated film shall be performed through tests conducted in special chambers that simulate conditions of the space environment. Note that measurements of optical properties and related changes due to exposure to the space environment in a vacuum are preferable.

$$\Delta\alpha_s = \alpha_{s1} - \alpha_{s0}$$

where

α_{s0} is the solar absorptance before test;

α_{s1} is the solar absorptance after test.

$$\Delta\varepsilon = \varepsilon_1 - \varepsilon_0$$

where

ε_0 is the emittance before test;

ε_1 is the emittance after test.

5.5 Thermal vacuum stability

a) Measurements shall be performed on the samples according to ASTM E595 or ECSS-ST-Q70-02. Another measurement method may be applied with the customer's approval. The measurement method shall be recorded and reported.

NOTE Thermal vacuum stability criteria depend on contamination requirements. The requirements depend on the spacecraft design and the impact of outgassing to sensitive equipment aboard spacecraft (sensors, solar array, optics, etc.).

b) When numerical contamination analysis is required, the outgassing rate shall be measured according to ASTM E1559 or ECSS-ST-Q70-02.

5.6 AO resistance

5.6.1 Product qualification test

The AO irradiation test shall be performed. The coated film shall be irradiated by 1 × 10^{21} atoms per square centimetre of AO fluence. AO flux, fluence, and type of test apparatus shall be measured and recorded.

Changes in the mass and thermo-optical properties of the tested specimen shall be evaluated. Other properties are assessed as required. The coated film is considered acceptable when the measured mass loss is less than 100 μg/cm^2.

NOTE These quantitative parameters in the test are defined from space environment model, its calculation and demonstration performance. This provides minimum screening criteria for materials in space use.

5.6.2 Life estimation test

The AO irradiation test should be performed. The amount of atomic oxygen received by a spacecraft is determined by the orbital altitude, expected lifetime, attitude, and geometry of the spacecraft. The coated film should be irradiated by the estimated AO fluence. AO flux, fluence, and type of test apparatus shall be measured and recorded.

Changes in the mass and thermo-optical properties of the tested specimen should be evaluated. Other properties are assessed as required.

5.7 UV resistance

5.7.1 Product qualification test

The UV irradiation test should be performed. The coated film shall be irradiated by 1 200 ESH of UV fluence. UV flux and fluence shall be measured and recorded.

Changes in the mass and thermo-optical properties of the tested specimen shall be evaluated. Other properties are assessed as required. The coated film is considered acceptable when the measured change of solar absorptance is less than 0,05.

NOTE These quantitative parameters in the test are defined for screening test of distinguishing low tolerance materials.

5.7.2 Life estimation test

The UV irradiation test should be performed. The amount of UV received by a spacecraft is determined by the orbital altitude, expected lifetime, attitude, and geometry of the spacecraft. The coated film should be irradiated by the estimated UV fluence. When the UV fluence is defined, the wavelength range shall be recorded. UV flux, fluence, and acceleration ratio shall be measured and recorded.

Changes in the thermo-optical properties of the tested specimen should be evaluated. Other properties are assessed as required.

5.8 Radiation resistance

5.8.1 Product qualification test

The electron beam irradiation test should be performed. The coated film shall be irradiated by 1×10^6 Gy of electron beam fluence. Electron beam flux and dose shall be measured and recorded.

Changes in the mass and thermo-optical properties of the tested specimen shall be evaluated. Other properties are assessed as required. The coated film is considered acceptable when the measured change of solar absorptance is less than 0,05.

NOTE These quantitative parameters in the test are defined for screening test of distinguishing low tolerance materials.

5.8.2 Life estimation test

The electron beam irradiation test should be performed. The dose received by a spacecraft is determined by the orbital altitude and expected lifetime of the spacecraft. The coated film should be irradiated by the estimated electron beam dose. Electron beam flux, dose, acceleration ratio, and particle energy should be measured and recorded.

Changes in the thermo-optical properties of the tested specimen should be evaluated. Other properties are assessed as required.

5.9 Adhesion

Adhesion of AO protective coating on the base film is determined by preferably using the tape stripping tests primarily performed on a witness sample. Other adhesion tests are also permissible.

The test specimen shall be of the same batch/lot as that of the coated film for flight.

After firmly adhering the cellulose tape (adhesive force ≥ 2 N / 10 mm) to the coated surface, pull the tape straight up with a certain force to peel it off from the coated surface.

Examples of cellulose tape include[1)]:

— CT-18 (Nichiban Co., Ltd.)

— Scotch Tape 600 A-A-113 (3M)

1) These are examples of suitable products available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of these products.

The actual way to peel off the tape is stipulated in ISO 2409 or ASTM D3359 APPENDIX without application of cuts.

5.10 Volume resistance

The electrical volume resistivity of coated film should be measured using measuring probes and an appropriate voltage or resistance meter. The samples should be at least 25 mm × 50 mm in size.

The probes should have high conductivity and provide good electrical contact on the entire contact surface with the sample, and should not interfere with the proper measurement of resistance of the sample under test.

Resistance measurements are performed using measuring devices that have the required accuracy and ability to perform measurements within a preset range, and which allow smooth regulation of the applied test voltage. Measurement shall be performed under a vacuum condition.

The measurements shall be performed according to ASTM D257. When charging analysis is performed to predict on-orbit charging condition, it is very important to acquire data about a time dependence of charging decay of material. In this purpose, materials data can be measured by charge storage method. Charge storage method irradiates electron beam on material sample in vacuum chamber. Volume resistance is calculated using decay time constant immediately after EB irradiation terminates. Since this test method has not been standardized, test conditions and parameters should be decided based on mature agreement of test requester and conductor.

5.11 Surface resistance

The electrical surface resistance of coated film should be measured using measuring probes and an appropriate voltage or resistance meter. The samples should be at least 25 mm × 50 mm in size.

The probes should have high conductivity and provide good electrical contact on the entire contact surface with the sample, and should not interfere with the proper measurement of resistance of the sample under test.

Resistance measurements are performed using measuring devices that have the required accuracy and ability to perform measurements within a preset range, and which allow smooth regulation of the applied test voltage. Measurement shall be performed under a vacuum condition.

The measurements shall be performed according to ASTM D257.

5.12 Secondary electron emission yield

The secondary electron emission yield of coated film should be measured using a pulsed electron beam. The beam was irradiated to the sample, and the current flowing to the sample and that flowing to the collector covering the sample were both measured. Here, −300 V and −250 V are applied to the sample and the collector, respectively. When the sample is an insulator, the measurement position is changed at every pulse of the electron beam.

5.13 Photoelectron emission yield

For the photoelectron emission coefficient, vacuum ultraviolet rays should be irradiated to the sample in pulses and the electron current emitted from the sample was measured. A wavelength selection filter was placed between the ultraviolet light source and the sample; and quantum efficiency was fitted from the photoelectron current curve obtained from each wavelength region.

5.14 Thermal cycling (influence of temperatures)

The thermal cycling test should be performed. Coated film shall function under the following conditions, unless otherwise stated in the standard for each coated film.

a) −190 °C to +200 °C, 200 cycles

b) −65 °C to +150 °C, 1 000 cycles

If the coated film is sensitive to oxidation reactions, it is desired to test under vacuum.

NOTE These quantitative parameters in the test are defined for screening test of distinguishing low tolerance materials.

The measurement of coated film durability to determine the influence of high and low temperatures, as well as temperature cycling, shall be performed in a special climatic chamber capable of simulating the correct environmental conditions.

Tests are performed on witness samples. Changes in the thermo-optical properties and adhesion of the tested specimen shall be evaluated. Other properties are assessed as required.

5.15 Repair/Retouch

Repair and retouch should be performed according to adequate documents issued by the coating supplier. Prior to repairing or retouching the coated film for flight, repair shall be simulated using a witness sample.

5.16 Cleaning

Cleaning shall be performed according to adequate documents issued by the coating supplier. Prior to cleaning the coated film for flight, cleaning shall be simulated using a witness sample.

6 Requirements and recommendations for application

6.1 Consideration for usage

a) AO protective coating shall have adhesion with the base film to which it is applied and be suitable for the intended use.

b) AO protective coating should be applied using any regulated method described in the coating's normative document.

c) Defects are described in materials' or application standards, or as specified in design documentation.

d) When assembling, manufacturing, marking, and during packing operations, the coated film shall not be touched and handled with bare hands. Lint-free clean cotton or powder-free surgical gloves shall be used.

When touched or handled with protected hands, the coated film shall not move against the coated surfaces.

e) Coating process requirements (regarding the method of application, work area, and safety measures) should be defined by the coating material supplier. All parameters that define the process requirements shall be properly controlled and monitored.

f) Failure modes: scratches, cracks, separations, chips, dirt, and uncoated spots during ground operations.

NOTE General coatings selection guideline is shown in Annex C.

Causes include assembly, transportation, wrapping, unwrapping, atmospheric conditions. When these defects are repairable, the repair procedures recommended by the appropriate coating supplier shall be followed.

6.2 Identification

a) Coated films shall be labelled.

b) The label shall contain all the information to identify unambiguously the coated film according to the normative documentation.

6.3 Protectors

Protectors are to protect coated film from damage and contamination during assembly, installation, and transportation.

The properties of applicable coated film protection materials are defined in accordance with the requirements of design documentation and by taking into consideration each material's technological normative document.

Coated film protection materials are applied, used, and removed in accordance with the process described in appropriate design documentation.

6.4 Packing

a) Coated film should be adequately packed for protection against damage and dirt during transportation and storage.

b) The type of package is chosen in accordance with the size and shape of the product to be packed, taking into consideration the materials and components of the product.

c) The type of package should be specified in the product specifications.

7 Production program of quality assurance

7.1 General

a) The person/organization responsible for application of the film coating should have an adequate quality management system, such as one with ISO 9001 certification.

b) The supplier should be requested to identify the production processes and actions that exert an influence on the properties of the components that are used to manufacture film coating, and should also provide adequate monitoring of these processes and actions.

c) The basic processes and actions for which appropriate procedures should be developed are as follows:

   1) incoming inspection (identification) of raw materials and components;

   2) storage of raw materials and components;

   3) production of film coating in working conditions;

   4) test methods of the finished products;

   5) marking, packing.

d) Certification: consumers should conduct the incoming inspection of coating to check whether the necessary indicators are in conformity with the certificate of the product.

7.2 Changes and revisions

Documents regarding as coated film production program of quality assurance shall be controlled according to ISO 27025:2010, 5.1.

7.3 Record of changes

All changes and revisions should be registered in the record of changes that includes the following:

a) the number of changes of the given copy;

b) the designation of the confirmatory document;

c) the date of change of the given copy;

d) the numbers of pages (changed, new and annulled);

e) the name and signature of the person responsible for making the changes.

Depending on the project phase, a Non-Conformance Review Board (NRB) shall be convened.

Annex A
(informative)

Types of coatings

A.1 ITO (indium tin oxide)

ITO provides a transparent oxide coating having high electrical conductivity. It is utilized for the purpose of AO protection and electrostatic charging mitigation. ITO coating slightly increases the absorptance, but does not change the emittance of its base film. ITO is usually applied by the CVD process.

A.2 SiO_x

SiO_x can provide a transparent coating. The typical SiO_x coating is mostly composed of SiO_2. It is utilized for the purpose of AO protection. SiO_x coating increases the emittance of its base film. SiO_x is usually applied by the CVD process.

A.3 Germanium

A germanium coating provides a gray coating. Its moderate surface resistance is utilized to mitigate static charge. Since a germanium coating is transparent in the RF spectrum, it is often used for the sunshields of RF antennae. Given its poor adhesion under humidity, germanium-coated film shall be stored in a moisture-free environment.

A.4 Silsesquioxane (SQ)

Organo-silsesquioxane (SQ) can provide a transparent organo-$SiO_{1.5}$ coating. By AO irradiation, a SiO_x ($x > 1,5$) layer is formed on the outermost surface of the SQ layer. The SiO_x layer protects the film from AO erosion. The SQ coating barely changes the absorptance and emittance of the base film. SQ is usually applied by the UV curable wet coating process.

A.5 Silicone

Silicones can provide a transparent coating resistant to AO. Under AO irradiation, silicone reacts to form SiO_2 layer on the outermost surface of the silicone coating. The SiO_2 layer protects the film from AO erosion. Silicone can be applied by spray gun pulverisation, then cured at 200 °C during 1 h.

A.6 Metal alloy

A metal alloy, such as silicon aluminum alloy coating provides a gray coating. It has the same optical and electrical properties as germanium, but increased resistance to corrosion.

Annex B
(informative)

General properties of atomic oxygen protective coatings

Table B.1 lists general properties of the atomic oxygen protective coatings in Annex A.

Table B.1 — General properties of atomic oxygen protective coatings

Properties	Test method	Test condition	Unit	Typical values					
				ITO	SiO_x	Germanium	Silsesquioxane	Silicone	Metal alloy
Visual characteristics	Visual	-	-	Transparent	Transparent	Gray	Transparent	Transparent	Gray
Coating thickness	Process control	-	nm	< 10	100	50 to 175	1 000	5 000 to 15 000	50 to 60
Solar absorptance: α_s	ISO 16378	On 25 µm thick Kapton® HN[a], aluminized on one side	-	≤ 0,45	≤ 0,4	≤ 0,5	≤ 0,3	< 0,39	≤ 0,5
Infra-red emittance: ε_n	ISO 16378	On 25 µm thick Kapton® HN[a], aluminized on one side	-	≥ 0,6	≥ 0,7	≥ 0,6	≥ 0,7	≥ 0,79	≥ 0,8
Electrical surface resistance	ASTM D257	Parallel or circle contact with two probes that are each one inch wide and are placed six inches apart	Ω/square	≤ 10^4	≤ 10^{14}	≤ 10^9	≤ 10^{16}	≥ 10^9	<10^8
Thermal vacuum stability	ASTM E595[b]	TML	%	< 0,7	< 0,7	< 1,5	< 0,9	< 0,29[d]	< 0,3
	ECSS-ST-Q70-02C[b]	CVCM	%	0,002	0,002	0,01	0,002	0,02	0,008
Adhesion	ISO 2409[c] ASTM D3359[c]	Stripping with Scotch tape[a]		No change	No change	No change	No change	No change	No change
Rubbing resistance	Rubbing 20 cycles with 80 g/cm² force on gauze	No change	-	No change	No change	No change	No change	No change	No change
Thermal cycling		−190 °C/+200 °C, 200 cycles		No change	No change	No change	No change	No change	No change
AO resistance		1×10^{21} atoms/cm²							
$\Delta\alpha$				< 0,01	< 0,01	< 0,01	< 0,01	< 0,02	< 0,01
$\Delta\varepsilon$				< 0,05	0	< 0,01	< 0,01	0	< 0,01
Erosion yield[e]			10^{-24} cm³/atom	0,01	< 0,000 8	0,01	0,05	0,01	0,01
UV resistance		50 ESD							
$\Delta\alpha$				< 0,1	< 0,1	< 0,1	< 0,1	< 0,1	< 0,1
$\Delta\varepsilon$				< 0,05	< 0,05	< 0,05	< 0,05	< 0,05	< 0,05
Radiation resistance		1×10^6 Gy							

[a] These are examples of suitable products available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of these products.

[b] These standards are equivalent.

[c] These standards are equivalent.

[d] This is the value of RML.

[e] Erosion yield is also called erosion coefficient.

