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TECHNICAL REPORT

Fibre optic interconecting devices and passive components –
Part 03-04: Reliability – Guideline for high power reliability of passive optical components

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FOREWORD

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IEC/TR 62627-03-04, which is a technical report, has been prepared by subcommittee 86B: Fibre optic interconnecting devices and passive optical components, of IEC technical committee 86: Fibre optics.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
86B/3641/DTR	86B/3676/RVC

Full information on the voting for the approval of this technical report 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.

A list of all the parts in the IEC 62627 series, published under the general title *Fibre optic interconnecting devices and passive components* can be found on the IEC website.

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- withdrawn,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

A bilingual version of this publication may be issued at a later date.

INTRODUCTION

Since 2000, the optical power in transmission systems has increased in conjunction with the increase in the number of channels for DWDM systems, with the deployment of RAMAN amplifiers and the application of optical amplifiers.

Several technical reports have been published on failure mode analysis, life-time estimation by accelerated aging tests, and other issues for passive optical components.

The long-term reliability for passive optical components is generally evaluated by accelerated aging tests such as a high temperature test, a damp heat test and a temperature cycling test. These tests are standardized and are included in reliability qualification test documents.

Although the failure mode for passive optical components under high power conditions has not been clarified, one technical report was published for specific passive optical components (IEC/TR 62627-03-02), and a technical report on high power reliability testing for metal doped fibre plug-style optical attenuators was proposed.

This technical report is prepared based on the knowledge contained within these two technical reports.

FIBRE OPTIC INTERCONECTING DEVICES AND PASSIVE COMPONENTS –

Part 03-04: Reliability – Guideline for high power reliability of passive optical components

1 Scope

This part of IEC 62627, which is a technical report, is a guideline for a procedure to evaluate the reliability of passive optical components under high power conditions. This guideline is one example to which the test results of IEC/TR 62627-03-02 and IEC/TR 62627-03-03 may apply.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60825-1, *Safety of laser products – Part 1: Equipment classification and requirements*

IEC 61300-2-14, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 2-14: Tests – High optical power*

IEC 61300-3-35, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-35: Examinations and measurements – Fibre optic endface visual and automated inspection*

IEC/TR 62627-03-02, *Fibre optic interconnecting devices and passive components – Part 03-02: Reliability – Report of high power transmission test of specified passive optical components*

IEC/TR 62627-03-03, *Fibre optic interconnecting devices and passive components – Part 03-03: Reliability – Report on high-power reliability for metal-doped fibre optical plug-style optical attenuators*

3 Generic information

IEC/TR 62627-03-02 describes the return losses of metal doped fibre plug-style optical attenuators degraded under high optical input power at around 2 W, and the fibre in the ferrule of in-line optical isolators breaking and causing isolation failure. The thermal simulation estimated that the maximum temperature for metal doped fibre plug-style optical attenuators and in-line optical isolators could reach several hundred degrees Celsius. It was estimated that the return loss degradation for metal doped fibre plug-style optical attenuators was caused by fibre withdrawal from the ferrule surface due to the thermal stress following a rise in temperature. It was believed that the optical isolator fibre breaks were caused by the stress created by the differences in thermal expansion coefficients of the materials from which the parts were made.

Passive optical components are generally composed of several parts with different shapes and materials. The typical failure mode under long-term operation is generally related to a change of shape and optical path displacement due to the dislocation of fixing points for constituent parts. To confirm the reliability against these failure modes, passive optical components are tested under temperature cycling, high temperature and high humidity conditions, all of which are more severe than nominal operating conditions. These tests are called accelerated aging tests. The temperature acceleration factor is commonly calculated by using the Arrhenius formula. The test duration time for these accelerated aging tests is typically several months. It is based on the belief that normal operation over a long period of time, i.e. over ten or more years should be assured. Typical acceleration factors are several hundred times that of nominal operating conditions for high temperature, high humidity and temperature cycling. If the factor is greater than a thousand, the test conditions may be too severe and produce different failure modes than those found in actual service. A lower acceleration factor value requires longer test duration.

The failure mode and the failure mechanism under high power conditions described in IEC/TR 62627-03-02 comes from the thermal stress caused by heat that is generated by the absorption of input optical power. It may be effective to use an accelerated aging test to assure long term operation of passive optical components under high power conditions. However, no life-time estimation model was determined and little evaluation data has been reported on the high power accelerated aging test. IEC/TR 62627-03-03 describes the estimated maximum input power that will assure long term operation. A similar approach found in the study of high power reliability for passive optical components seems to be useful and effective.

4 Procedures for confirmation of high power reliability

The following describes the procedure for the estimation and confirmation of maximum input power to assure the long-term reliability for passive optical components:

a) develop a high power risk table to analyse the failure mode under the high power input condition for passive optical components;
b) estimate the failure mechanism using the high power risk table;
c) carry out a high power step-stress test for optical components or for the parts considered likely to fail;
d) identify the damage threshold power from the result of the high power step-stress test. Disassemble the components to analyse the failure mode, or carry out a thermal simulation, if needed. Identify the failure mechanism from the step-stress test result, the failure mode analysis and the risk analysis table. Estimate the maximum input power that can assure the long-term reliability based on the step-stress-test result and the thermal simulation;
e) carry out a long-term reliability test under high power conditions. Use the samples with the lowest performance to effectively find the failure mode and the failure mechanism.

5 Risk analysis under high power conditions

5.1 Example of risk under high power conditions

Generally, passive optical components consist of several types of parts and materials. There are some typical failure modes for some specific parts and materials under high power conditions. Table 1 shows the summary of the typical failure modes.

A typical failure mode for coating films on the crystals, prisms or lenses under high power conditions is the coating film damage due to increasing temperature caused by absorbing the light. The colour-centre is sometimes the trigger of absorption. The colour-centre may be produced by a lattice defect. It is known that the toughness of the coating film depends on the material of the film as well as the deposition method of the film.

An optical semiconductor such as PD (photo diode) under high power conditions fails due to the material change caused by the excess electrical current in a small region.

$LiNbO_3$ substrates fail due to the increase in propagating loss by photorefractive effect when the $LiNbO_3$ is irradiated by high power visible light.

The failure mode under high power conditions for other materials is a change in quality due to temperature increases caused by the absorption of light. For example materials such as adhesive resins can change in quality or soften at a relatively low temperature.

A rise of internal temperature of optical components induces a thermal stress among constituent parts having different thermal expansion coefficients. The thermal stress deforms the parts and degrades the performance of the components.

A temperature rise of specific parts can cause an unequal thermal distribution in components. Thermal stress induced deformation due to an unequal thermal distribution is a common failure mechanism for passive optical components under high power conditions.

Table 1 – Typical risks of materials on high power input condition

Materials	Components/modules	Failure modes
TFF coating (AR coating)	Almost all components and modules	Coating film damage due to increasing temperature by absorbing light
Semiconductor	LDs, PDs, APDs	Material change by excess current
LCD	VOAs, WSSs, WBs	Insertion loss increasing by absorption (Visible light, UV)
$LiNbO_3$	Modulators	Insertion loss increasing by photorefractive effect
Garnet	Isolators, circulators, VOAs	Damage due to increasing temperature by absorbing light
Metal doped fibre	Optical attenuators	Fibre withdrawal due to increasing temperature by absorbing light
Connector endface	Optical connectors	Damage of endface due to burnt contamination, etc. Insertion loss by scattering light at scratches
Adhesive	Waveguide devices, mechanical splices, etc.	Change in quality and softening due to increasing temperature by absorbing light
Silicone	BOSA for BIDIs, AWGs	Material changing due to increasing temperature by absorbing light
Refractive index matching liquid	Optical switches, AWGs, etc.	Material changing due to increasing temperature by absorbing light

5.2 Preparation of risk analysis table

To analyse the risk level under high power conditions for passive optical components, it is useful to summarize risk factors in a table for all optical parts and their supporting parts in the optical path of passive optical components. This analysis method is similar to FMEA (failure mode effect analysis) used to determine component reliability risks.

Table 2 shows an example of the format for a high power risk analysis table. It is usually recommended to summarize information about the parts in the optical path, materials, beam diameters, optical power densities, failure modes, influences on performance of optical components, severity levels, and the failure mechanism of components.

It is also necessary to consider the operating wavelength range of optical components. At this point, it should be verified that there are no input errors not only in the operating wavelength range but also in the neighbouring wavelength range.. Moreover, it should be considered that users may input wavelengths other than the specified operating wavelength range. In order to prepare a risk analysis table, all potential applications should be considered. When there are materials whose failure modes depend on wavelength, it is necessary to list specific wavelength(s) to have an accurate assessment of the risk of failure.

High power risk analysis tables for metal doped fibre plug-style optical attenuators, in-line optical isolators, and optical splitters are shown in Annex A, as examples.

Table 2 – Format of high power risk analysis table

Units	Parts	Materials	Beam diameters	Power densities	Failure modes	Influences to performance	Severity levels	Failure mechanisms

5.3 Estimation of failure modes and determination of test conditions

Risks and likely failure modes under high power conditions can be analysed using Tables 1 and 2. The risk factors should be summarized for different wavelength ranges and input/output ports, if necessary.

6 Step-stress test

6.1 General

A step-stress test should be carried out for the DUT (device under test), or for parts considered likely to fail. IEC 61300-2-14 describes the detail procedure of the step-stress test of high power damage threshold power characterization.

If it is likely that the failure modes are due to a quality change in some specific materials, the material itself should be tested before testing components to determine the beam density to be used.

6.2 Test set-up

The recommended test set-up for a high power test is shown in Figure 1. The laser safety should be confirmed to comply with IEC 60825-1 before the test is started. Fusion splices should be used to connect all of the optical components. Where connectorized components are utilized, connector interfaces should be inspected to be in compliance with IEC 61300-3-35. Any special optical components used to block the backward propagation of the fibre fuse phenomena, or long fibres used to detect the fibre fuse phenomena should be inserted between the high power light source and the first 20 dB coupler as shown in Figure 1. Fused fibre type optical branching devices should be used for power monitoring. The branching ratio of optical branching devices should be 20 dB or more. Individual 1×2 optical branching devices for input power monitoring (PM1) and for reflected power monitoring (PM3) should be used. This configuration can eliminate the influence of reflection from the optical connector fibre endface of input power monitor (PM1) to the reflected power monitoring (PM3). For safety purposes, at the end of the test setup, an optical termination such as metal doped fibre should be connected as shown in Figure 1.

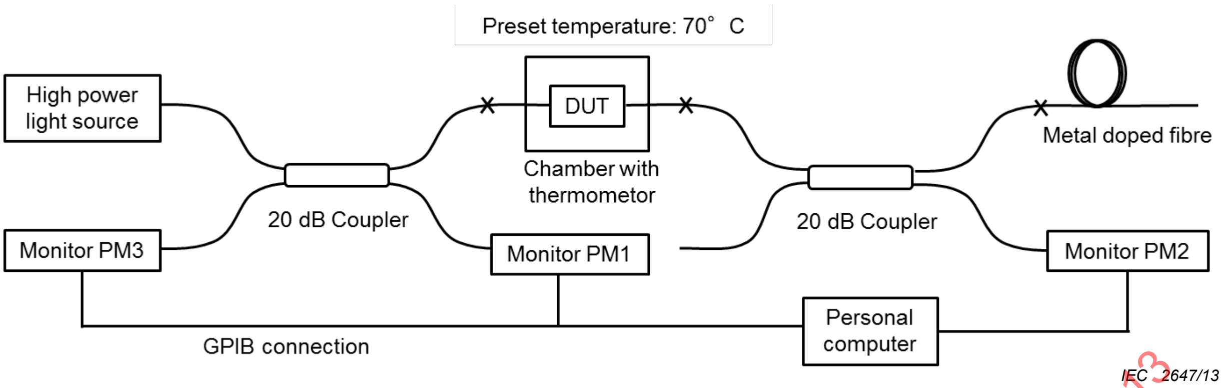

Figure 1 – Test set-up of high power step-stress test (example)

6.3 Test condition

6.3.1 Duration time of step-stress test

When determining the duration time of a step-stress test, it is necessary to consider the failure modes. Failure of the coating film, failure of semiconductor devices, and photorefractive effects occur within a relatively short period of time typically less than a few minutes, depending on the input power level. In the case of the failure mode being a temperature increase by the absorption of light, the temperature stability time of optical components should be considered. Typical temperature stability times for metal doped fibre plug-style optical attenuators and in-line optical isolators are around 10 min to 20 min, as described in IEC/TR 62627-03-02. The temperature stability time depends on the thermal capacity of DUT. Larger optical components or larger modules may require a longer time to stabilise. A duration time of 30 min is generally recommended if there are no specific requirements.

6.3.2 Test temperature

The test temperature shall be determined and should be the maximum operating temperature of the component, especially if the failure mode is caused by an internal temperature increase due to the absorption of light. IEC 61300-2-14 defines a test temperature of 70 °C.

6.3.3 Pass/fail criteria

IEC 61300-2-14 describes the pass/fail criteria as an increase of 0,5 dB insertion loss. Pass/fail criteria in IEC/TR 62627-03-02 is an insertion loss deviation of 1 dB and a return loss decrease of 10 dB. When determining the pass/fail criteria, it is necessary to consider the application in which the components are used. It is recommended to use the pass/fail criteria of insertion loss deviation of 0,5 dB and a minimum return loss value as given in a specification unless other requirements are provided.

6.3.4 Performance monitoring

When determining what performance is monitored in a step-stress test, it is necessary to consider the influences on the performance shown in the risk analysis table. Insertion loss and return loss should be monitored.

6.3.5 Test wavelengths of light source

When the internal materials are wavelength dependant, the wavelengths liable to cause degradation should be listed. The test wavelength of the light source should be determined to suit the application. At this point, it should be checked that there are no input errors, not only in the operating wavelength range, but also in the neighbouring wavelength range. Moreover, it should be understood that users may input wavelengths other than those of the specified operating wavelength range.

All of the specified operating wavelengths should be considered for the test. If the failure mode for each wavelength can be identified, the highest risk wavelength should be selected. For branching devices, the common port should be used to input optical power, and the output power levels monitored at the branching ports. If there is more than a 10 dB difference of input power level in different wavelengths, the wavelength with the highest power level should be selected for the test. For DWDM devices that operate over more than one spectral band, and when the materials used in the optical paths have low wavelength dependency, one nominal wavelength may be used for the test.

6.3.6 Test power

When determining the initial power level of step-stress test, it is necessary to consider the component application and the insertion loss of the components. The power level should be raised to the level at which the failure of the DUT occurs.

The step size in the step-stress test is defined in IEC 61300-2-14. It is recommended to increase the power level in increments of 10 % or 20 %. A smaller step size is better than a larger step size, as a larger step size may lead to higher uncertainty of the damage threshold power. If the step size is too small, the total test time may be increased unduly.

6.3.7 Sample size

The sample size shall be a minimum of three units. In cases where the failure mode is due to filter film failure, the samples should be picked from different deposition lots as the toughness of the film may depend on the deposition lot.

6.3.8 Coherency of light source

The coherency of light source for the test should be determined after considering how the components are used. Where the failure mode is a coating film failure, the damage threshold power may depend on the coherency of the light source.

7 Analysis of step-stress test result

7.1 Estimate and identify the failure mechanism

The damage threshold power and the failure mechanism shall be identified based on the result of the step-stress test. It is strongly recommended to disassemble damaged DUTs for the purpose of identifying the failure mechanism. If the quality of the material has changed, a material analysis of that part shall be performed. A reflection meter may be used to identify if a fibre is broken, as given in IEC/TR 62627-03-02, which describes the results of the analysis of a failed in-line optical isolator.

Where the failure mechanism is due to a temperature increase by the absorption of light, thermal simulation or examination of the disassembled failed DUT is a useful way to identify the failure mechanism. IEC/TR 62627-03-02 reports the results of thermal simulation by FEM (finite element method) for metal-doped, fibre plug-style optical attenuators, in-line optical isolators and waveguide-type optical splitters. It is reported that the internal maximum temperature for metal doped fibre plug-style optical attenuators can reach 120 °C when the input optical power is 1 W. Thermal stress simulation is as useful as thermal simulation when estimating deformation due to stress caused by the differences of the thermal expansion coefficients of materials. Using the analysis methods mentioned above, the failure mechanism can be identified for high power conditions.

7.2 Estimate the maximum input power for guaranteeing long-term reliability

Adhesive resin is commonly used for manufacturing passive optical components. The glass transition temperature (T_g) of resin is relatively low. To check the long-term reliability, T_g

should be tested and analysed. When optical components include resin, T_g influences on the estimated maximum input power should be identified in order to assure long-term reliability

If the failure mode is coating film damage, optical semiconductor device failure or a photorefractive effect, and if the damage threshold power level is determined by the step-stress test result, the estimated maximum input power at which the device can be expected to operate reliably over the long-term is the maximum power level that the DUT can tolerate in the step-stress test.

If the failure mechanism cannot be identified after disassembling the failed DUT and reviewing the thermal simulation result, and the likely failure mechanism cannot be determined based on the risk analysis table, it is recommended that the maximum input power for assuring long-term reliability should be 80 % of the maximum input power level that the DUT can tolerate at the step-stress test. When the failure mechanism cannot be identified from the risk analysis table but can be estimated by temperature increase, the estimated maximum input power level that can assure the long-term reliability should also be limited to 80 % of the maximum input power of the stress test.

When the DUT has not failed because the maximum power of the high power light source is limited, the estimated maximum input power that can assure long-term reliability is 80 % of maximum input power used in the test.

The estimated maximum input power that can assure long-term reliability can be estimated from the above analyses and studies.

8 Long-term test

It is necessary to carry out the long-term high power test at a power level that can assure the long-term reliability and that was determined from the step-stress test of the DUT, thermal simulation result or other methods. The test time should be 500 h or longer.

The test set-up and the test temperature is the same as that of the step-stress test. In order to minimize the time and effort for setting up the test, several DUTs can be connected serially. For WDM devices, the test should be carried out at the highest risk wavelength determined from the results of the step-stress test and the risk analysis table.

The sample size should be greater than or equal to eleven, in order to meet a goal of a maximum 20 % LTPD (lot tolerance percentage defective).

If it is desired to minimize the sample size, DUTs should be selected from the lowest performance samples or samples that can reproduce the failure mode, degradation levels and the failure mechanism.

If the failure mode is damage of coating film, the damage threshold power level may depend on the deposition lot and care should be taken when selecting the samples.

9 Reliability under high power conditions

The maximum input power level that can assure long-term reliability can be estimated from the procedures described in Clause 4, the detailed methods described in Clause 5 and the test methods described in Clause 6.

For commercial purposes, the recommended maximum input power level is 70 % or 50 %, of the maximum power level that is determined by this procedure, unless the failure mechanisms are well understood and the manufacturing variance is known and controlled.

10 Test report

A test report should be prepared after the test. The test report should include the risk analysis table, the results of step-stress testing including the detailed test conditions, the result of additional analysis such as investigative disassembly, thermal simulation and the result of long-term testing including the detailed test conditions.

Annex A
(informative)

Examples of high power risk analysis table for optical passive components

Tables A.1 to A.3 show high power risk analysis tables for metal doped fibre plug-style optical attenuators, in-line optical isolators and waveguide type optical splitters.

Table A.1 – High power risk analysis table for metal-doped, fibre plug-style fixed optical attenuators

Units	Parts	Materials	Beam diameters µm	Failure modes	Influence to performances	Severity level	Failure mechanisms
Fibre and ferrule	Metal doped fibre and ferrule	Metal-doped fibre, etc.	10	Fibre withdrawal due to softened adhesive	RL degradation	Medium	Temperature increasing by absorbing light
Fibre facet	Fibre facet	SiO_2	10	Fibre withdrawal due to softened adhesive	RL degradation	Medium	Heat-up by scattering by scratch, dot.
				Fibre fuse	Fibre fuse phenomena	High	Temperature increasing by burning contamination

Table A.2 – High power risk analysis table for in-line optical isolators

Units	Parts	Materials	Beam diameters µm	Failure modes	Influence to performances	Severity level	Failure mechanisms
Collimator	Lens	Glass	300	None	NA	NA	NA
	Lens AR	TiO_2/SiO_2 etc.	10	Coating film damage	RL degradation	Low	Quality change due to absorbing light
	Ferrule	ZrO_2	10	Fibre break	Insertion loss increasing RL degradation	High	Thermal stress by absorbing light
Isolator unit	Faraday rotator	Garnet	300	Faraday rotator angle change	Insertion loss increasing Isolation decreasing	Medium	Temperature increasing by absorbing light
	Birefringent crystal	TiO_2, LN, YVO_4	300	None	NA	NA	NA