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First edition
2004-08

Optical amplifiers –

Part 4: Maximum permissible optical power for the damage-free and safe use of optical amplifiers, including Raman amplifiers

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OPTICAL AMPLIFIERS –

Part 4: Maximum permissible optical power for the damage-free and safe use of optical amplifiers, including Raman amplifiers

FOREWORD

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IEC 61292-4, which is a technical report, has been prepared by subcommittee 86C: Fibre optic systems and active devices, of IEC technical committee 86: Fibre optics.

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

Enquiry draft	Report on voting
86C/593/DTR	86C/629/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.

IEC 61292 consists of the following parts, under the new general title *Optical amplifiers:*

Part 1: Parameters of amplifier components

Part 2: Theoretical background for noise figure evaluation using the electrical spectrum analyzer

Part 3: Classification, characteristics and applications

Part 4: Maximum permissible optical power for the damage-free and safe use of optical amplifiers, including Raman amplifiers

Part 5: Polarization mode dispersion parameter – General parameter

Future standards in this series will carry the new general title as cited above. Titles of existing standards in this series will be updated at the time of the next edition.

The committee has decided that the contents of this publication will remain unchanged until the maintenance result 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- withdrawn;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

This technical report is dedicated to the subject of maximum permissible optical power for damage-free and safe use of optical amplifiers, including Raman amplifiers. Since the technology is quite new and still evolving, amendments and new editions to this document can be expected.

Many new types of optical amplifiers are entering the marketplace and research on this subject is also stimulating many new types of fibre and non-fibre based optical amplifier research. With the introduction of such technologies as long-haul, 40Gb/s, WDM transmission and Raman amplification, some optical amplifiers may involve optical pump sources with extremely high optical power – up to, possibly, several watts.

Excessively high optical power may cause physical damage to the fibres/optical components/equipment as well as present medical danger to the human eye and skin.

The possibility of fibre damage caused by high optical intensity has recently been discussed at some technical conferences. IEC Technical Committee 31 (Electrical apparatus for explosive atmospheres) is also discussing the risk of ignition of hazardous environments by radiation from optical equipment.

The medical aspects have long been discussed at standards groups. IEC Technical Committee 76 (Optical radiation safety and laser equipment) precisely describes in IEC 60825-2 the concept of hazard level and labelling and addresses the safety aspects of lasers specifically in relation to tissue damage.

ITU-T Study Group 15 (Optical and other transport networks) has published Recommendation G.664, which primarily discusses the automatic laser power reduction functionality for safety.

With the recent growth of interest in fibre Raman amplifiers, however, some difficulties have been identified among optical amplifier users and manufacturers in fully understanding the technical details and requirements across all such standards and agreements.

This technical report, therefore, provides a simple informative guideline on the maximum optical power permissible for optical amplifiers. To the best of our knowledge, this is the first international guideline on the maximum optical power permissible in optical fibre devices that takes both physical and medical viewpoints into consideration.

OPTICAL AMPLIFIERS –

Part 4: Maximum permissible optical power for the damage-free and safe use of optical amplifiers, including Raman amplifiers

1 Scope and object

This technical report applies to all commercially available optical amplifiers (OAs), including optical fibre amplifiers (OFAs) using active fibres, as well as Raman amplifiers. Semiconductor optical amplifiers (SOAs) using semiconductor gain media are also included.

This technical report provides a simple informative guideline on the threshold of high optical power that causes high-temperature damage of fibre. Also discussed is optical safety for manufacturers and users of optical amplifiers by reiterating substantial parts of existing standards and agreements on eye and skin safety.

To identify the maximum permissible optical power in the optical amplifier from damage-free and safety viewpoints, this technical report identifies the following values:

– the optical power limit that causes thermal damage to the fibre, such as fibre fuse and fibre-coat burning;
– the maximum permissible exposure (MPE) to which the eyes/skin can be exposed without consequential injury;
– the optical power limit in the fibre that causes MPE on the eyes/skin after free-space propagation from the fibre;
– the absolute allowable damage-free and safe level of optical power of the optical amplifier by comparing (a) and (c).

The objective of this technical report is to minimize potential confusion and misunderstanding in the industry that might cause unnecessary alarm and hinder the progress and acceptance of advancing optical amplifier technologies and markets.

It is important to point out that the reader should always refer to the latest international standards and agreements, because the technologies concerned are rapidly evolving. In fact, the concept of hazard level and labelling is still evolving: more rigorous labelling requirements are under discussion in IEC Technical Committee 76 as of October 2003.

The technical report will be frequently reviewed and will be updated by incorporating the results of various studies related to OAs and OA-supported optical systems in a timely manner.

2 Maximum transmissible optical power to keep fibres damage-free

The use and reasonably foreseeable misuse of high intensity optical amplifiers may cause problems in the fibre such as:

a) fibre fuse and its propagation;
b) heating in the splice point/connection point;
c) fibre end-face damage due to dust and other contamination;
d) fibre coat burning and ignition of hazardous environments due to tight fibre bending or breakage.

This clause introduces the experiments and their results concerning the above issues to give guidelines for the damage-free use of optical amplifiers. However, it must be noted that the following results are only valid under the conditions tested and that a higher power might be allowed under different conditions.

2.1 Fibre fuse and its propagation

2.1.1 Introduction

The safety of optical amplifiers should be discussed from the viewpoint of laser hazard to the eyes and skin as well as fibre damage such as fibre-coat burning and fibre fusing. This document experimentally analyzes the fibre fuse and its propagation caused by high optical power and discusses the threshold of optical power.

2.1.2 Experiment and results

The experimental setup is shown in Figure 1, in which the fibre fuse was initiated by heating the optical fibre from outside of the fibre by using an independent heat source, while a high optical power was continuously launched into the fibre. The wavelength of the high-power optical source was 1 467 nm, which is a typical pump wavelength for distributed Raman amplification.

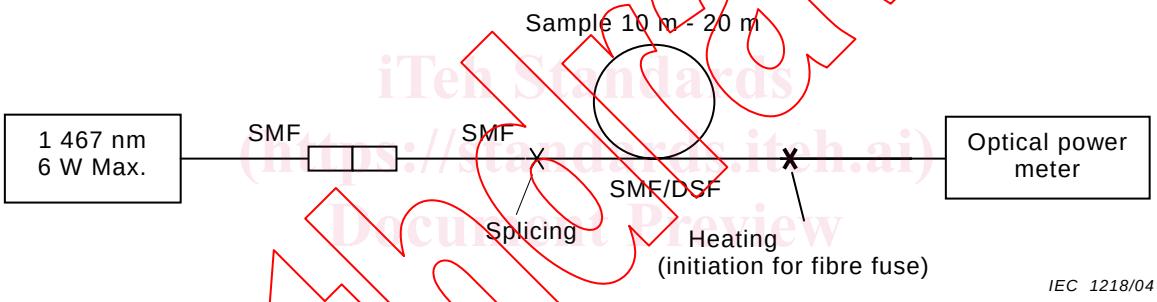

Figure 1 – Experimental setup for fibre fuse propagation

It was confirmed that the temperature of the fibre portion heated when the fuse initiated was greater than 1 000 °C. Once the fibre fuse began propagating, the optical source power was continuously reduced until the fuse propagation stopped. The threshold power for the fuse propagation was 1,4 W and 1,2 W for standard single mode fibre (SMF) and dispersion shifted fibre (DSF) respectively, as shown in Table 1. The results for three trials are shown.

Table 1 – Experimental results of the threshold power of fibre fuse propagation

Standard single mode fibre	1,41 W, 1,45 W, 1,51 W
Dispersion shifter fibre	1,19 W, 1,19 W, 1,20 W

The difference in the fibre mode-field diameter might have been the major reason for the difference in the threshold powers, because the fibre fuse depends on the power density [1][1)]. The threshold power for the fibre fuse propagation was quite reproducible.

On the other hand, it was difficult to identify the threshold power for the fibre fuse initiation based on the above experiments, because it varied significantly.

1) Figures in square brackets refer to the Bibliography.

Although the mechanism of fibre fuse initiation is not yet well understood, the threshold seems to depend on the conditions, i.e., clean or dirty, of the fibre end faces where the very first fibre fuse takes place.

It was confirmed through repeated experiments, however, that the initiation threshold well exceeded 1,2 W and 1,4 W for various fibre end-face conditions.

The above information was made available from Furukawa Electric (Japan in Oct. 2002) and was reported [1] at the 2003 International Laser Safety Conference in Jacksonville, FL, USA.

This issue was also discussed in other literature [3] as follows.

The main physical mechanism responsible for the fibre fuse phenomenon and its propagation is optical discharge propagation due to thermal conductivity. It can be initiated in most fibre types by launching a CW laser into a fibre and ensuring contact of the fibre output end face with some absorbing surface or by heating a section of the fibre.

The temperature of the optical discharge plasma is about 5 000° to 10 000 °K. The speed of its propagation is about 1m/s in typical single mode fibres at a laser power of approximately 1 W. Examination of the fibre core after such discharge reveals extensive damage in the form of voids which have the form of bubbles (sometimes periodic) or long non-periodic filaments.

Because the most probable reason for optical discharge is a contaminated end face, fusion splicing is the most reliable way to reduce the risk of high-power damage. Optical isolators used in some schemes can also be damaged. Unfortunately, their survivability at high power is an open question.

The literature [3] includes a figure reporting the measured dependencies of threshold intensity for the propagation of optical discharge through the fibre (the power at which such propagation is terminated) on the mode field diameter of single-mode fibres of different core compositions.

The figure includes 21 data points for the mode field diameter (MFD) between 2 μm and 14 μm and identifies that the mean values of the threshold intensity I_{th} were 3,6 MW/cm^2, 2,5 MW/cm^2 and 1,2 MW/cm^2 for the MFD of 4 μm, 6 μm and 8 μm , respectively. I_{th} was constant at 1,2 MW/cm^2 for MFD over 8 μm.

The I_{th} varied between +0,3 MW/cm^2 and –0,6 MW/cm^2, depending on the core compositions under the conditions tested, except in one extraordinary case. Here, the mean thresholds for the MFD of 8 μm and 10 μm respectively corresponded to 2,5 W and 1,6 W, if the entire intensity is assumed to be within the mode field

2.1.3 Conclusion

The threshold optical powers of fibre fuse propagation reported in Figure 1 and Table 1 were found to be 1,4 W and 1,2 W for SMF and DSF respectively under the conditions tested. On the other hand, the fuse-initiation threshold varied significantly, although they well exceeded 1,4 W and 1,2 W. Another report identified that a little more power than the above experiment could be allowed, although the information available on the fibre was limited.

2.2 Loss-induced heating at connectors or splices

2.2.1 Introduction

In extremely high power optical amplifiers, the loss-induced heating at fibres and connectors or splices could lead to damage, including fibre-coat burning, fibre fuse, etc. This subclause provides experimental data [1] and considerations for information.