Optical Fiber Technology xxx (2013) xxx–xxx

Contents lists available at ScienceDirect

Optical Fiber Technology

www.elsevier.com/locate/yofte

Comparative study on the degradation of UV optical fibers subjected to electron beam and gamma ray irradiation

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ARTICLE INFO

Article history:
Received 13 July 2013
Revised 27 September 2013
Available online xxxx

Keywords:
Bremsstrahlung irradiation
Electron beam irradiation
Gamma-ray irradiation
H2-loaded optical fibers
Radiation induced attenuation
Radiation resistance

ABSTRACT

The present paper continues our previous research on the degradation of UV optical fibers under irradiation and reports, as a novelty in the filed, a comparative study on the radiation induced optical attenuation in three commercial available, UV optical fibers subjected to electron beam, gamma ray and bremsstrahlung irradiation. The purposes of these investigations were on one side to evaluate the radiation sensitivity of UV optical fibers under conditions not reported previously in the literature and, on the other side, to estimate the possible use of various types of such optical fibers for radiation detection/monitoring. The dependency of the optical attenuation at specific wavelengths was measured as a function of the optical fiber type and irradiation conditions, such as dose rate, total dose, and temperature stress applied during the irradiation. In this paper, we investigate also the behavior of H2-loaded UV optical fiber with metal coating when irradiation and heating are applied simultaneously. H2-loading of UV optical fibers proved to be a reliable mean to increase the radiation hardness in the case of UV optical fibers, and sample heating during the irradiation affect less the Al coated optical fibers than polyimide coated ones. A linear dependency of the optical attenuation on the total dose was observed for H2-loaded samples and in the case of solarisation resistant optical fibers. We suggest that a proper balance between radiation hardening and sensitivity to radiation of UV optical fibers can pave the way towards their use in radiation monitoring.

1. Introduction

In general, two aspects are considered when investigating the behavior of optical fibers subjected to irradiation conditions: (a) the resistance of these fibers under irradiation exposure; (b) the way the degradation of optical fibers can be used in radiation detection/ monitoring [1,2]. The idea to use the change of the optical attenuation for radiation dosimetry/monitoring was promoted in several papers [3–14]. In previous studies, H2-loaded optical fibers operating at communication wavelengths, in the visible and near-IR range, were investigated [15,16]. Our original contributions in the field refer to tests carried out on UV optical fibers [17,18].

This paper presents a comparative study on the radiation induced optical attenuation in the case of three types of multimode, UV optical fibers subjected to electron beam, gamma ray and bremsstrahlung irradiation. The dependency of the optical attenuation, at specific wavelengths on the irradiation conditions was measured in situ.

We report, **for the first time**, the results related to: (a) multimode UV optical fibers tested under electron beam irradiation; (b) evaluation of the optical attenuation change under bremsstrahlung, as compared to gamma ray exposure; (c) the effect of Al coating of UV H2-loaded optical fibers.

For some Al-coated optical fibers we investigated also the effect of H2 loading and heating during the irradiation. At specific wavelengths, in H2-loaded optical fibers an improved radiation resistance was observed. One of our previous paper indicated that sample heating during the irradiation of H2-loaded optical fibers with polyimide buffer increases the radiation sensitivity of the optical fiber, as a result of outwards H_2 diffusion [17]. This effect is less evident for H2-loaded optical fibers with Al buffer reported in this paper. In the present paper, we studied new types of optical fibers, different from previous reported.

The conclusions of the present paper, corroborated with our previous results [17,18], indicate that appropriate selection of the optical fiber characteristics, the irradiation type (i.e. electron beam, gamma ray, bremsstrahlung, neutrons in a nuclear research reactor), and the irradiation conditions (dose rate, total dose, heating during the irradiation, etc.) can constitute the base for the use of UV optical fibers degradation for radiation monitoring.

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http://dx.doi.org/10.1016/j.yofte.2013.10.005

2. Materials and experimental

The optical fiber samples we investigated fall into three different categories: (a) standard OH, high fluorine concentration silica clad (Fiberguide, SFS400/440/480T and Z); (b) common solarization resistant (Ocean Optics, 400SR); (c) solarization resistant, H2-loaded (Fiberguide, UV200/220H2A). They are commercially available, produced by two manufacturers. Some of the investigated Al-coated optical fibers can be operated under high temperature; consequently we applied heating during the irradiation. Table 1 details the characteristics of the investigated optical fibers and the irradiation conditions to which they were subjected. OFS is the sample nickname - optical fibe sample. Considering the great diversity of materials and testing conditions, this preliminary study compares the effect of OH, H2-loading, Al-coating and temperature stress on the radiation resistance of UV optical fibers. For this purpose, UV optical fibers with different characteristics are evaluated. The role of the dose rate on the optical attenuation degradation is also considered.

The evaluation of the irradiation effects was done by on-line measurements of the optical attenuation during radiation exposure, in the UV–visible spectral range (200–850 nm), using a set-up based on an optical fiber spectrometer (0.5 nm spectral resolution, integration time from 3 ms to 60 s, 12 bit data conversion), a deuterium–tungsten light source (maximum output fluctuation better than 0.005% p–p, after a 30 s warm-up time), an optical fiber manual attenuator (having a spectrally flat attenuation between 0% and 98% transmission, from 200 nm to 2000 nm), and an optical fiber multiplexer (2×8 inputs configuration, switching time of <60 ms for adjacent positions, optical throughput of about 60%, optical repeatability > 90%) [17]. In Fig. 1, a generic presentation of the experimental setup is illustrated, valid for all irradiation related measurements, with and without heating. In the case the same type of optical fiber is irradiated both at room temperature and under heating conditions, the two samples (7 and 8) are connected as in Fig. 1, one of them being exposed both to ionizing radiation (10 – irradiation source) and heating (6 – heating device). The light from a broadband, very stable light source (1) is transmitted through an optical fiber attenuator (2) and the input section of an optical fiber multiplexer (3) to the samples to be investigated (7 and 8). The other ends of the samples are connected through the output section of the optical fiber multiplexer (4), one by one, to an optical fiber spectrometer (5). All the instruments were controlled by a laptop through a dedicated software package, based

Table 1
The characteristics of the investigated optical fibers and the irradiation conditions.

Sample designation	Optical fiber type	Core/ cladding diameter (μm)	Buffer diameter (μm)	Irradiation conditions
OFS1	– Solarization resistant – H_2-loaded – Step-index – multimode – Pure fused silica core/fluorine doped silica cladding – NA = 0.22	200/220	Al 308	Bremsstrahlung; dose rate: 9 Gy/min; room temperature; circular geometry irradiation set-up; sample length 200 mm
OFS2	– Solarization resistant – H_2-loaded – Step-index – Multimode – Pure fused silica core/fluorine doped silica cladding – NA = 0.22	200/220	Al 308	Bremsstrahlung; dose rate: 9 Gy/min; $T = 513$ K; circular geometry irradiation set-up; sample length 200 mm
OFS3	– Solarization resistant – H_2-loaded – Step-index – Multimode – Pure fused silica core/fluorine doped silica cladding – NA = 0.22	200/220	Al 308	^{60}Co gamma-ray; dose rate: 90 Gy/min; room temperature; circular geometry; irradiation set-up sample length 200 mm
OFS4	– Solarization resistant – H_2-loaded – Step-index – Multimode – Pure fused silica core/fluorine doped silica cladding – NA = 0.22	200/220	Al 308	^{60}Co gamma-ray; dose rate: 90 Gy/min; $T = 513$ K; circular geometry irradiation set-up; sample length 200 mm
OFS5	– Standard OH – Step-index – Multimode – Pure fused silica core/fluorine doped silica cladding – NA = 0.22	400/440	Polyimide 480	Electron beam; dose rate: 2 kGy/min; room temperature; linear geometry irradiation set-up; sample length 73 mm
OFS6	– Standard OH – Step-index – Multimode – Pure fused silica core/fluorine doped silica cladding – NA = 0.22	400/440	Silicon 590 Tefzel coating	^{60}Co gamma-ray; dose rate: 110 Gy /min; room temperature; linear geometry irradiation set-up; sample length 200 mm
OFS7	– Solarization resistant – High hydroxyl content	400	Polyimide	^{60}Co gamma-ray; dose rate: 110 Gy/min; room temperature; linear geometry irradiation set-up; sample length 200 mm

Please cite this article in press as: D. Sporea et al., Comparative study on the degradation of UV optical fibers subjected to electron beam and gamma ray irradiation, Opt. Fiber Technol. (2013), http://dx.doi.org/10.1016/j.yofte.2013.10.005