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Microarticle

Application of phosphate doped fibers for OFDR dosimetry

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ABSTRACT

We employ phosphate doped optical fibers for distributed dosimetry based on Optical Frequency Domain Reflectometry (OFDR) and demonstrate the effect of limited Integrated Insertion Loss Dynamic Range (ILDR) on the system performance.

In the data sheet of the OFDR analyzer two dynamic ranges are certified: the Integrated Return Loss Dynamic Range (RLDR) and Integrated Insertion Loss Dynamic Range (ILDR) [1]. The RLDR is declared to be ~70 dB and defines the ability of the OFDR analyzer to measure strong local back reflections such as Fresnel reflections. The ILDR is significantly lower than RLDR and commonly specified for standard telecom fibers (Corning SMS-28) as ~16 dB (for double pass). The lower boundary of ILDR is determined by the apparatus noise, while the upper boundary is the Rayleigh backscattering level. The apparatus noise depends on the particular configuration of the optical fiber network and could be significantly influenced by the data processing algorithm. Therefore, the actual ILDR is several dB less than the difference between the Rayleigh backscattering level and the noise level [2]. The ILDR is important for distributed dosimetry [3], since it determinates the range of radiation induced absorption (RIA) detectable without significant errors. Here we apply a radiation sensitive phosphate doped fiber for OFDR radiation experiment and demonstrate the saturation effects associated with a limited ILDR at total dose.

The experiment was performed with a 63-cm sample of phosphate doped radiation-sensitive fiber manufactured by FORC RAS with phosphorus oxide molar concentration of 13.0%. The test fiber was connected to the OFDR analyzer (OBR 4400, Luna Technology) through two lengths of the standard telecom fiber (Corning SMS-28), ~17 m length each, and exposed uniformly to gamma radiation from Co^{60} source with a rate of 566 Gy/h during 160 h [4]. Rayleigh scattering traces were recorded each 8 min with a spatial resolution of 38 μm and then averaged over 15 cm along the fiber length. Recording of OFDR traces was altered with independent monitoring of the total RIA in the fiber at 1550 nm by a superluminescent source and OSA. The fiber temperature of 60 °C was maintained constant during the experiment.

Fig. 1 shows zoomed segments of the OFDR traces recorded before (curve 1) and just after irradiation with the total dose of ~90 kGy (curve 2). Points z_a and z_b correspond to splices between

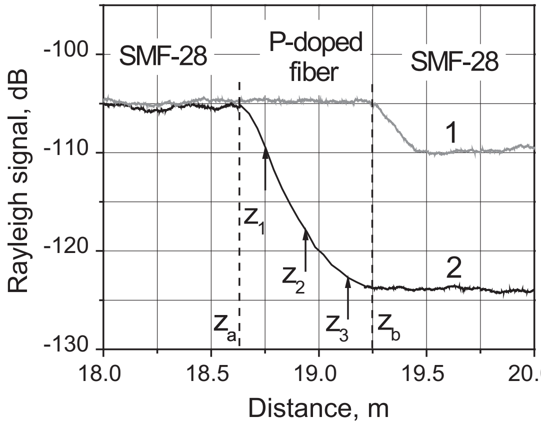

Fig. 1. A segment of the OFDR trace recorded before (curve 1) and after irradiation (curve 2). z_a = 18.60 m, z_1 = 18.75 m, z_2 = 18.94 m, z_3 = 19.13 m, z_b = 19.23 m.

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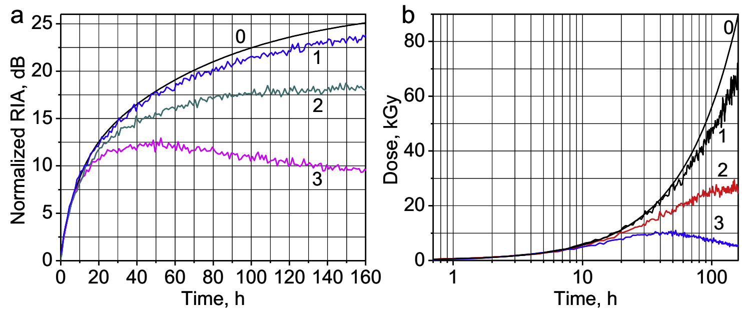

Fig. 2. The normalized RIA (a) and absorbed dose (b) reconstructed from OFDR measurements in points $z_1 = 18.75$ m, $z_2 = 18.94$ m, $z_3 = 19.13$ m (curves 1–3) and OSA data (curve 0).

the telecom and test fibers. One can see from the original trace (curve 1) that the normalized Rayleigh backscattering levels are the same, −105 dB, in both fibers. The level of the apparatus noise is −123 dB, so ILDR is estimated to be ~16 dB (for double pass). The RIA induced in the fiber by gamma-radiation leads to a gradual decrease of the backscattering signal toward the fiber end. In the beginning of the tested fiber (z_1) the signal decreases linearly along the fiber length indicating uniform RIA induced by uniform irradiation of the fiber. However, for more distant points (z_2, z_3) the linear decrease of the signal slows down and falls into the noise floor highlighting the measurement saturation effect associated with a limit of ILDR. This behavior is rather general and depends on the ILDR value and the fiber sensitivity. For comparison, similar traces are observed at the dose of ~50 kGy with Al-doped fibers [2].

Fig. 2a presents the temporal evolution of the RIA (normalized on total fiber length L) obtained from OFDR traces. Three different curves correspond to different points along the fiber length as shown in Fig. 1. The curve 1 (z_1) demonstrates the highest RIA increase and is in an agreement with the RIA measured by OSA (curve 0). However, curves 2, 3 defining RIA in points z_2 and z_3, respectively, deviate significantly from the OSA calibration curve. The closer the point to the fiber end the stronger the saturation effect. Dynamics of the absorbed dose D shown in Fig. 2b has been reconstructed from RIA data as reported in [5]. The curves 1–3 in comparison with the calibration curve 0 demonstrate how the error of measurements in different fiber points increases with the increase of the absorbed dose. The error is attributed to the fact that the optical signal decays as it propagates through the fiber, and the total induced losses at the observation distance exceed the reserve of ILDR. With the increase of the absorbed dose the saturation occurs at smaller distances z, so shorter length of the fiber becomes available for distributed sensing. It is worth noting that all fiber points are accounted by the OFDR algorithm to reconstruct the Rayleigh signal distribution along the fiber from the measured fiber reflectivity spectrum [1]. Therefore, the detection noise associated with signal saturation in far fiber points could affect the accuracy of the Rayleigh reflectivity restoration in near points. For example, in the point z_1 the ILDR limit of 16 dB is not achieved during the experiment (the corresponding RIA level is 16 dB$(z_1 - z_a)/2L \sim 33$ dB). However, the error of the dose measurement in z_1 increases with the dose and exceeds ~15% at ~90 kGy due to the saturation occurring in far fiber points $z > z_1$. An error of 20% is attained at a dose of ~10 kGy in z_3 (curve 3), thus defining the capabilities of the system for distributed dose measurements in all points. The system dosimeter range could be extended up to 10MGy by optimizing the fiber composition and the whole sensor structure [3].

In conclusion, we believe that the reported experimental results highlight features important for OFDR based dosimetry. The work was supported by IAP program VII/35 of the Belgian Science Policy and Ministry of Education and Science of the Russian Federation (RFMEFI57714X0074).

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