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IRRADIATION TESTS ON OPTICAL FIBERS BELOW 20 K

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I. INTRODUCTION

Optical fibers are used routinely in harsh environments for signal transmission or sensing applications [1]. Whereas the individual challenges originating from very high or very low temperatures, vacuum or ionizing radiation were extensively studied, the effects of combinations of these conditions were not investigated widely.

It is well known that temperature can influence the radiation response of optical fibers drastically. Tests at one temperature are not necessarily transferable to environments with other temperature conditions. Already 1975 Mattern et al. investigated the attenuation increase in optical fibers caused by ionizing radiation at temperatures between 217 K and 344 K [2]. Halperin and Ralph investigated the influence of temperature in bulk Ge-doped quartz between 77 K and 600 K even earlier [3]. Most of the irradiation tests on optical fibers were done in a relatively limited temperature range. Higher temperatures were investigated mostly for the installation in nuclear facilities, for example Hawn et al. presented extensive results up to 873 K [4].

At lower temperatures only very few results were published, especially below 100 K. Only three papers report on irradiation tests between 77 K and 89 K [5]-[7]. Of those Barnes and Griscom did not compare the results with data obtained at room temperature and Söderqvist included no directly comparable results.

Systematic data of radiation-induced attenuation in optical fibers as a function of temperature is only available within a limited range with lowest temperature values of 152 K and 300 K [2],[8]-[21]. West gave a review of the temperature related effects and data available at the time [22]. The temperature range covered by this existing data is mainly defined by the foreseen applications and the relevant standards, such as MIL-PRF-49291 that demands tests between 227 K and 358 K.

Figure 1 shows the data of the available measurements so far. As a function of temperature the relative radiation-induced attenuation normalized to room temperature is plotted. Only data of Ge-doped or un-doped optical fibers (if the composition was specified) is shown, the doses were roughly in the range of 100 Gy(SiO_2) to 1000 Gy(SiO_2). If available, data around 1310 nm was chosen for the graph. Some of the publications cited above did not report values at room temperature and thus are not included.

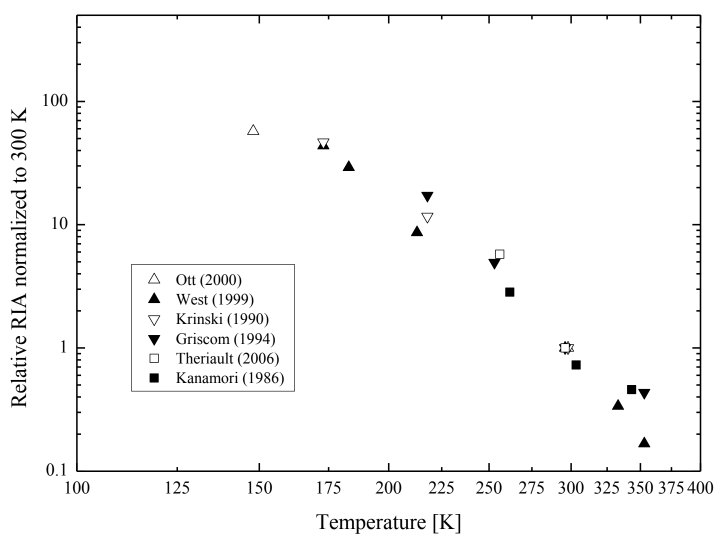

Fig. 1. Overview of temperature dependence measurements of RIA in optical fibers

Other investigations at lower temperatures looked at the effects of Hydrogen [23], photo-bleaching efficiency [24] or the influence of coating materials [12].

Up to now no comparison of radiation test results on optical fibers at room temperature and below 150 K was done. However, in some applications much lower temperatures will define the environment, for example at cryogenic accelerator installations or space missions. Qualifying optical fibers for these conditions demands tests at lower temperatures than achievable with liquid Nitrogen or liquid Argon.

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II. EXPERIMENTAL

The investigated fiber is a SMF28e manufactured by Corning, in order to compare the results to other data published before (see Figure 1) and to test the cryo-setup in comparison to our standard setup [21].

The fiber is coiled loosely around a copper spool of 60 mm diameter. The length used at room temperature was 100 m and at 16 K the length was 1 m. Care was taken to not stress the fiber due to thermal expansion of the cryo-setup or the fiber itself.

Our setup consists of three light sources to measure the attenuation change in the fiber online during cooling, heating and irradiation. The power of two discrete precision light sources at 1312 nm and 1570 nm is monitored with calibrated powermeters (HP8153A). Using optical switches also spectral data is taken with an Advantest TQ8111 white light source and an OceanOptics NIRquest array spectrometer.

Using a coupler a second path is serving as a reference channel. The fibers for the reference channel are guided inside of the sample chamber and back and only the short leads of that path are exposed to the gamma radiation. The data obtained in the measurement channel is then compensated with the reference path.

Low temperatures were achieved with a Closed Cycle Cryostat, Model DE204SF manufactured by ARS. A sample chamber is mounted on the second stage of the cryostat and filled with helium exchange gas in order to ensure good thermal coupling of the fiber; the feed-throughs from the outside to the helium atmosphere in the sample chamber are designed to be room temperature. Two cernox sensors at the second stage and inside the sample chamber monitor the temperature, as well as two fiber-bragg gratings within the fiber-spool. An additional head-shield coupled to the first stage of the cryostat and the outer vacuum-chamber complete the cryo-setup. The inevitable vibrations of the Gifford-McMahon type cryo-cooler did not influence the optical measurements. Neither the attenuation measurements nor the very sensitive bragg-grating measurements show any significant effect, weather the cryo-cooler was switched on or off, or in the cooling phase. Figure 2 depicts the setup as it was installed at the Co-60 facility.

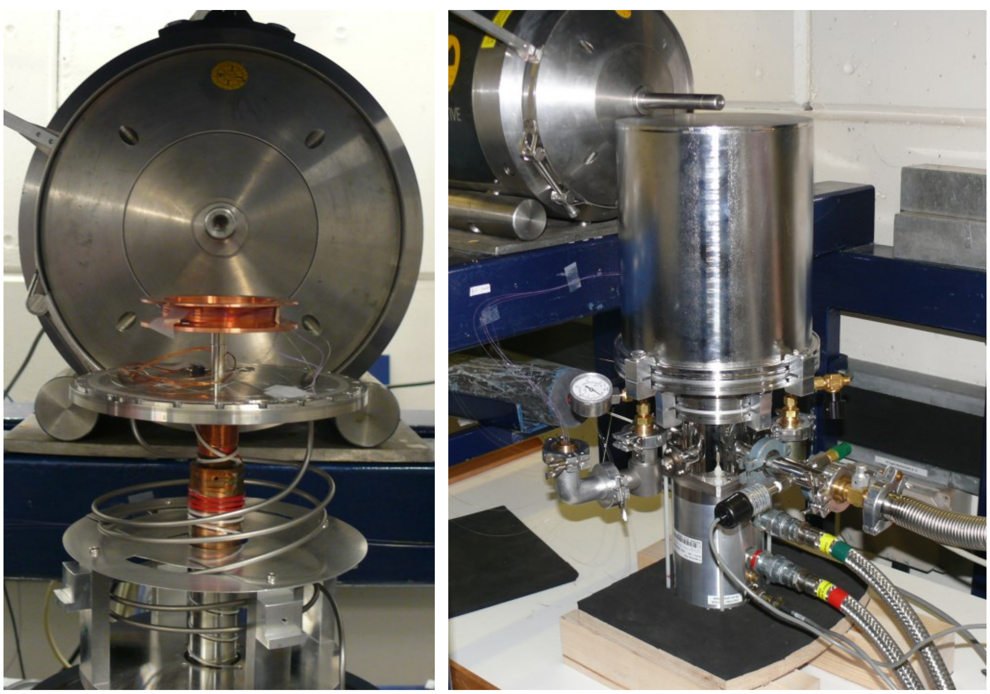

Fig. 2. Cryostat open and closed with installed sample fiber at the Co-60 irradiation facility

The irradiations were done at the TK1000A Co-60 gamma facility at the Fraunhofer INT. Calibrated ionizing chambers were used for dosimetry. The dose-rate in the samples was 0.26 Gy(SiO_2)/s and the irradiation time was 70.000 s.

To ensure optimal comparison of the cooled results at 16 K and those obtained at room temperature, the room temperature irradiation was also performed using the same setup inside the cryostat shown in Figure 2. The stability of the optical power was monitored throughout the whole setup of the experiment, starting with the splicing of the samples into the light path, establishing the helium atmosphere in the sample chamber, evacuating the heat shield chamber, running the cryostat at room temperature and cooling down to the base temperature.

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Also the temperature change from room temperature down to 16 K did not change the transmission of the fiber significantly. Previous tests reported large fluctuations during the cooling of the fiber caused by micro-bending effects [25], which were not observed in our setup. The change of optical power during the cooling phase is shown in Figure 3. The relative change of optical power at both wavelengths is given as a function of temperature. After reaching the lowest temperature of 16 K the measurement continued and indicates the overall stability in cooling condition (visible in the dotted oval in Figure 2). The overall variation during cooling and stability phase is less than 0.1 dB for both wavelengths.

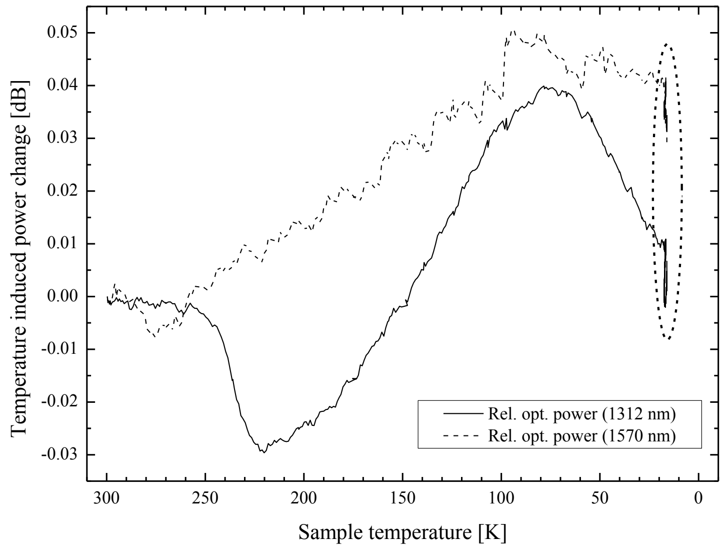

Fig. 3. Temperature induced attenuation in sample fiber in dB between 300 K and 16 K

III. RESULTS AND DISCUSSION

Figure 4 shows the results of two irradiations at room temperature and at 16 K, respectively. In both cases the radiation-induced attenuation is given at 1312 nm and 1570 nm in dB/km to account for the different sample length used up to nearly 20 kGy(SiO_2).

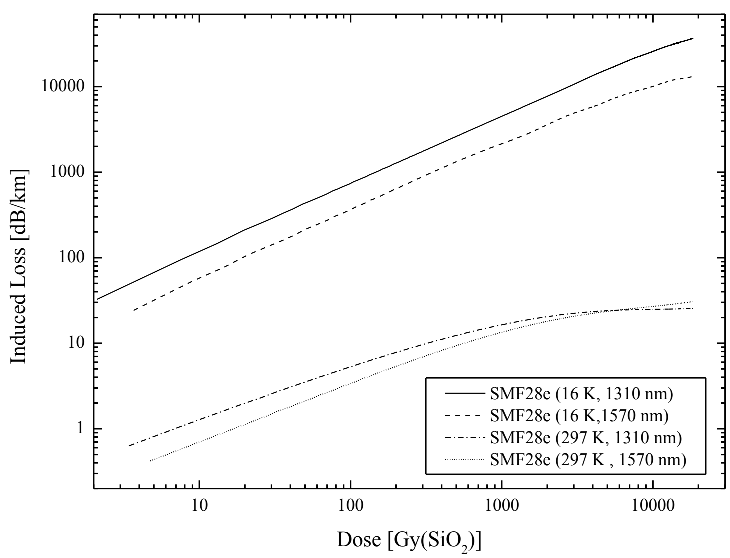

Fig. 4. Radiation-induced attenuation at 300 K and 16 K for two wavelengths in a Ge-doped SMF

The values at room temperature are typical for this kind of fiber and in perfect agreement with tests done before in our lab, even though the fibers are in Helium atmosphere and mounted on the cryostat. Together with the previously shown stability measurement during the cooling phase one can expect to limit the difference of

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the results at 16 K compared to room temperature to the effect of radiation exposure at another temperature, excluding potential other effects originating from temperature behavior of the coating or bending effects.

The total induced loss in the samples at 1312 nm was 2.6 dB at room temperature and 36.6 dB at 16 K.

The induced losses at 16 K are orders of magnitude higher than at room temperatures for both wavelengths. Saturation seems to be shifted to higher doses and the typical cross-over of 1312 nm and 1570 nm curves is not present. From this data it is obvious that even for short lengths of the fiber, the induced attenuation leads to a dramatic decrease of transmission at 16 K.

From Figure 1 it is evident that the general behavior between radiation-induced attenuation and temperature is strongly correlated. Except for some other fiber types, such as P-doped fibers, a large increase of RIA takes place if the temperature is lower, as expected.

Figure 5 compares the data of Figure 1 to the value obtained in this work.

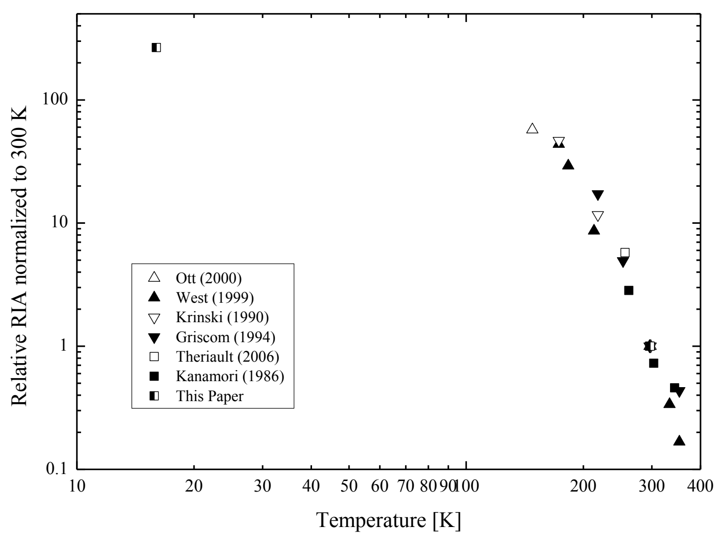

Fig. 4. Ratios of RIA as a function of temperature

The data presented in this paper follows the trend of the data from Figure 1. As shown by West [22], the RIA increase is lower than extrapolations of the previous data suggests.

It should be noted that depending on the selected dose and wavelength the RIA increase factor is even higher at 16 K. A qualification at room temperature is not sufficient to estimate the operation possibilities at very low temperatures.

IV. OUTLOOK AND CONCLUSION

Only a small part of the data gained in this experiment could be presented in this paper. Future analysis will be dedicated to the spectral dependence of the radiation-induced loss between 1000 nm and 1900 nm. Also the temperature information measured with the fiber-bragg gratings and their influence by the radiation will be investigated. Additional information will be gained by the study of the annealing curves at 16 K and the following heating period.

First tests on other types of single-mode fibers were started and will provide more data for the application of optimized radiation-tolerant optical fibers at low temperatures.

It has been shown that the radiation-induced attenuation in Ge-doped single-mode fibers is strongly depending on the temperature during irradiation. Applications at very low temperatures are faced with potential transmission losses that cannot be obtained by extrapolation of data measured at limited temperature ranges.

For the first time a comparison of the losses at room temperature and at 16 K was presented.

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REFERENCES

[1] S. Girard, J. Kuhnhenn, A. Gusarov, B. Brichard, M. Van Uffelen, Y. Ouerdane, et al., "Radiation Effects on Silica-Based Optical Fibers: Recent Advances and Future Challenges," IEEE Transactions on Nuclear Science, vol. 60, pp. 2015-2036, 2013.
[2] P. L. Mattern, L. M. Watkins, C. D. Skoog, and E. H. Barsis, "Absorption Induced in Optical-Waveguides by Pulsed Electrons as a Function of Temperature, Low-Dose Rate Gamma-Rays and Beta-Rays, and 14 Mev Neutrons," IEEE Transactions on Nuclear Science, vol. 22, pp. 2468-2474, 1975.
[3] A. Halperin and J. E. Ralph, "Optical Studies of Anisotropic Color Centers in Germanium-Doped Quartz", The Journal of Chemical Physics, vol. 39, pp. 63-73, 1963.
[4] D. P. Hawn, C. M. Petrie, T. E. Blue, and W. Windl, "In-situ gamma radiation induced attenuation in silica optical fibers heated up to 600 degrees C," Journal of Non-Crystalline Solids, vol. 379, pp. 192-200, 2013.
[5] C. E. Barnes, "Irradiation and Photobleaching of All-Silica, Pure Silica Core Fibers at Low Temperatures," Proceedings of SPIE, vol. 404, pp. 47-54, 1984.
[6] D. L. Griscom, "Growth and Decay Kinetics of Defect Centers in High-Purity Fused Silicas Irradiated at 77 K with X-Rays or 6.4-eV Laser-Light," Nuclear Instruments & Methods in Physics Research Section B, vol. 46, pp. 12-17, 1990.
[7] J. Söderqvist, L. O. Eek, J. Collot, J. P. Coulon, B. Dinkespiler, J. Y. Hostachy, et al., "Radiation hardness evaluation of an analogue optical link for operation at cryogenic temperatures," IEEE Transactions on Nuclear Science, vol. 44, pp. 861-865, 1997.
[8] M. Ott, "TID Radiation Induced Attenuation Testing at 1300 nm Using ISS Requirements on Three Optical Fibers Manufactured by Lucent SFT, " Internal Report to Lucent SFT (now called OFS). Available: http://misspiggy.gsfc.nasa.gov/photonics/, last accessed 2014-08-14, 2000.
[9] R. H. West, "Predicting the radiation induced loss in Ge doped optical fibres at different temperatures," Proceedings of the Fifth European Conference on Radiation and Its Effects on Components and Systems, pp. 483-490, 1999.
[10] J. A. Krinsky and M. Reddy, "Ionizing Radiation-Induced Attenuation in Optical Fibers at Multiple Wavelengths and Temperature Extremes," Proceedings of SPIE, vol. 1366, pp. 191-203, 1990.
[11] S. Share, R. M. McCracken, and I. Aggarwal, "Effect of Temperature on the Response of Glass-Clad Optical-Waveguides to Ionizing-Radiation," IEEE Transactions on Nuclear Science, vol. 25, pp. 1288-1292, 1978.
[12] E. W. Taylor, L. J. Myatt, and J. D. Wiltse, "Low-Temperature Gamma-Irradiation Response of Polymer Coated Optical-Waveguides," Proceedings of SPIE, vol. 404, pp. 55-59, 1984.
[13] D. L. Griscom, M. E. Gingerich, and E. J. Friebele, "Model for the Dose, Dose-Rate and Temperature-Dependence of Radiation-Induced Loss in Optical Fibers," IEEE Transactions on Nuclear Science, vol. 41, pp. 523-527, 1994.
[14] C. E. Barnes and J. J. Wiczer, "X-Ray-Induced Transient Attenuation at Low-Temperatures in Polymer Clad Silica (PCS) Fibers," Proceedings of SPIE, vol. 296, pp. 25-34, 1981.
[15] E. W. Taylor, J. M. Emmes, W. R. Ayres, J. D. Wiltse, and J. M. Maier, "Response of Irradiated Optical-Waveguides at Low-Temperatures," Proceedings of SPIE, vol. 296, pp. 40-50, 1981.
[16] R. H. West, "Temperature-dependence of radiation-induced losses in fiber optics," Electronics Letters, vol. 20, pp. 905-906, 1984.
[17] S. Theriault, "Radiation effects on COTS laser-optimized graded-index multimode fibers exposed to intense gamma radiation fields," Proceedings of SPIE, vol. 6343, p. 63431Q, 2006.
[18] H. Kanamori, H. Yokota, G. Tanaka, M. Watanabe, Y. Ishiguro, I. Yoshida, et al., "Transmission Characteristics and Reliability of Pure-Silica-Core Single-Mode Fibers," Journal of Lightwave Technology, vol. 4, pp. 1144-1150, 1986.
[19] R. H. West, "Temperature dependence of radiation induced losses in optical fibres," in Proceedings of OPTO '86, Paris, pp. 456-460, 1986.
[20] I. Yoshida, M. Watanabe, G. Tanaka, H. Yokota, H. Kanamori, S. Okamoto, et al., "Temperature and dose-rate dependence of radiation damage in single-mode fibers," in Proceedings of OFC 1986, p. TuI2, 1986.
[21] J. Kuhnhenn, S.K. Hoeffgen, and U. Weinand, "Quality Assurance for Irradiation Tests of Optical Fibers: Uncertainty and Reproducibility," IEEE Transactions on Nuclear Science, vol. 56, pp. 2160-2166, 2009.
[22] R. H. West, "Radiation effects on fibre optics," Proceedings of the SPIE, vol. 867, pp. 2-9, 1988.
[23] B. D. Evans, "The Role of Hydrogen as a Radiation Protection Agent at Low-Temperature in a Low-OH, Pure Silica Optical Fiber," IEEE Transactions on Nuclear Science, vol. 35, pp. 1215-1220, 1988.
[24] A. H. Johnston, B. D. Evans, M. P. Baze, and R. A. Greenwell, "Photobleaching effects in step index pure silica optical fibers during in-situ irradiation at low temperatures," Proceedings of the SPIE, vol. 867, pp. 25-31, 1988.
[25] E. J. Freibele, K. L. Dorsey, and M. E. Gingerich, "Optical Fiber Waveguides for Spacecraft Applications," Proceedings of the SPIE, vol. 721, pp. 98-103, 1986.

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