Influence of coating material, cladding thickness, and core material on the radiation sensitivity of pure silica core step-index fibers

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Abstract—**We investigated the influence of core material, cladding thickness, drawing speed, and coating material on the radiation sensitivity of pure silica core step-index fibers with high OH-content. The gamma radiation-induced attenuation at 660 nm and 850 nm of fibers by different manufacturers are compared.**

Index Terms— **Ionizing radiation, optical fibers, pure silica core fibers, radiation-induced attenuation**

I. INTRODUCTION

For use as a continuous Cherenkov detector at high energy electron accelerators, optical fibers have to withstand very high radiation doses in some cases. They can reach up to some hundred Gray within very short time if the electrons hit the beam tube, generating a secondary radiation shower that penetrates the fiber. A nearly unchanged transmission of the generated light is desired to enable comparable measurements of the Cherenkov signals over longer time periods. Degraded fibers cannot easily be replaced due to limited access times at large accelerators. Therefore the most radiation insensitive fiber has to be used. It is known that for light of shorter wavelength like Cherenkov light, fibers with an undoped SiO_2 core of high OH-content and a Fluorine-doped cladding show the lowest induced losses [1] - [4].

Meanwhile there exist several new manufacturers of preforms and core material for the production of such fibers. In the preparation for a comparative study, some manufacturers agreed to cooperate in investigating the influence of several production parameters on the radiation sensitivity of their fibers. In previous papers [5], [6] it was stated that fibers coated with polyimide show better radiation resistance. Moreover in [5] fibers with a lower cladding-core diameter ratio (CCDR) have been identified to have a higher radiation resistance. The same behavior was confirmed and partly explained later on [7]. We examined this behavior with current fibers produced by different manufacturers.

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II. EXPERIMENTAL

A. Fiber samples

All fiber samples had a core diameter of 200 µm. The cladding diameter was 220 µm for the 1.1-CCDR fibers (abbreviated **1.1**) and 240 µm for the 1.2-CCDR fibers (**1.2**). From all fibers we compared samples with polyimide (**PI**) and acrylate (**AC**) coating. Some fibers with acrylate coating were drawn at normal speed (**S**) and some with a lower speed (**L**) typical for the production of polyimide coated fibers. This was supposed to separate the effect of the lower drawing speed of polyimide coated fibers from the different treatment of the fibers during the application of the coating.

One manufacturer (**A**) used core materials from two different manufacturers (**E + F**), one of which (**E**) is also the supplier of a second fiber manufacturer (**B**). One company (**C**) was not willing to provide us with details of neither their suppliers nor their production methods. The fourth manufacturer (**D**) produces the core material and the preform but does not draw the fibers.

The preforms produced by the companies A and C were drawn by the manufacturers. The preforms by B and D were drawn by FiberWare (Mittweida, Germany) under identical conditions.

In the coding scheme, the first letter designates the producer of the preform (A, B, C or D). The supplier of the core material is given by the second letter (D, E, F or unknown). After that the CCDR is given, followed by the coating material (AC or PI). The last letter indicates the drawing speed (S, L or unknown). This parameter and the manufacturer of the core material is not known for the fiber manufacturer C. All samples are listed in detail in Table I.

B. Experimental methods

The fiber test samples had a length between 30 and 50 m and were irradiated at room temperature at the Gammamat TK1000 ^{60}Co irradiation facility of the Fraunhofer INT. The total dose was 10 kGy(SiO_2) at a dose rate of 0.3 Gy/s. For each measurement the fiber was wound up to spools with a diameter of 11 cm with the point source located in the centre of the spool. The radiation-induced loss of the fibers was monitored with LED sources and a HP8153A power meter at wavelengths of 660 nm and 850 nm. The light power was

TABLE I
LIST OF SAMPLES AND WAVELENGTHS AT WHICH THE INDUCED ATTENUATION WAS MEASURED

	AE1.1ACL	AF1.1PIL	AF1.1ACL	AF1.1ACS	BE1.1PIL	BE1.1ACL	BE1.1ACS	BE1.2PIL	BE1.2ACL	BE1.2ACS	C?1.1AC?	C?1.1PI?	DD1.1PIL	DD1.1ACL	DD1.1ACS	DD1.2PIL	DD1.2ACL	DD1.2ACS
Preform manufacturer	A	A	A	A	B	B	B	B	B	B	C	C	D	D	D	D	D	D
Core manufacturer	E	F	F	F	E	E	E	E	E	E	?	?	D	D	D	D	D	D
CCDR	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.1	1.1	1.1	1.1	1.1	1.2	1.2	1.2
Coating material	AC	PI	AC	AC	PI	AC	AC	PI	AC	AC	AC	PI	PI	AC	AC	PI	AC	AC
Drawing speed	L	L	L	S	L	L	S	L	L	S	?	?	L	L	S	L	L	S
Wavelengths [nm]	660	660	660	660	660/ 850	660/ 850	660/ 850	660/ 850	660/ 850	660/ 850	850	850	660/ 850	660/ 850	660/ 850	660/ 850	660/ 850	660/ 850

1 µW. A reference channel was used to compensate for drifts of the light source. The induced attenuation was measured continuously during irradiation and the subsequent annealing. In total, 30 irradiations were performed (see Table I).

III. RESULTS

The results are introduced in four sections. The first section presents the induced attenuation for selected samples at both wavelengths. In the following three sections a comparative analysis of the influences of coating material, CCDR, and core manufacturer is given.

Not shown are the results for different drawing speeds. Because of the rather small difference of only a factor of two we did not observe any significant influence for all tested samples.

A. Radiation-induced attenuation at 660 nm and 850 nm

Fig. 1 shows the radiation induced attenuation for selected samples at 660 nm. For two manufacturers (B and D) two samples with different CCDR are compared with a sample produced by company A. Whereas the difference of radiation sensitivity for fibers with different CCDR is very high for manufacturer B, the opposite is true for the samples by D. The behavior with increasing dose is distinctively different for the samples from the three manufacturers. For lower doses the sample AF1.1.ACL has the highest attenuation increase. But for dose values of more than 25 Gy the BE1.2ACL sample shows the largest losses.

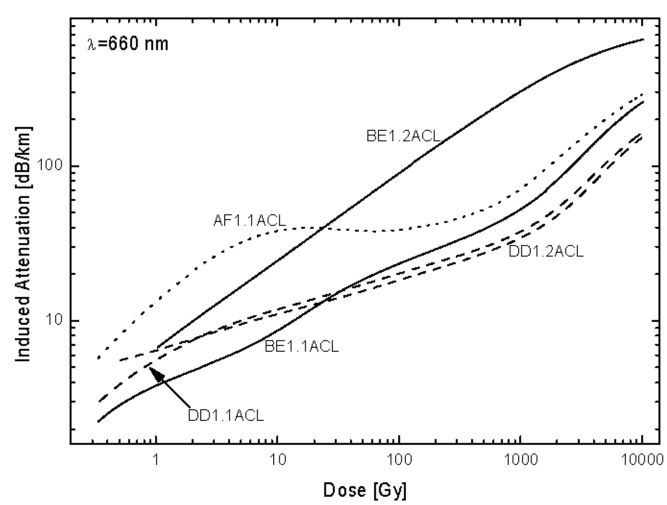

Fig. 1: Radiation-induced attenuation for selected fibers measured at 660 nm. The fibers produced by manufacturer D do not show a strong dependence on the CCDR. In contrast to this, the fibers by B with a CCDR of 1.1 show a much lower attenuation increase than those with a CCDR of 1.2 (See Fig. 4).

In Fig. 2 selected curves for measurements at 850 nm are presented. As for the results at 660 nm the attenuation increase with dose is different for samples from different manufacturers. Again the induced loss for sample BE1.2ACL is rather high for high dose values. Striking is the curve for the sample C?1.1AC?. Its radiation-induced attenuation is by a factor of 5 to 10 higher than that of the other investigated samples.

B. Influence of coating material

Different processes are used to apply the coating. While acrylate is cured with UV light the polyimide is cured at high temperatures up to 400 °C. It has been suggested that these high temperatures lead to a post-drawing anneal [6]. These results were obtained for only one preform which was drawn under identical conditions but coated with different materials. In contrast to this the diffusion of hydrogen released from the acrylate coating was proposed as an explanation for a better performance of acrylate coated fibers [7]. No comparison of different preforms and manufacturers was made.

Our results for the dependence on the coating material are

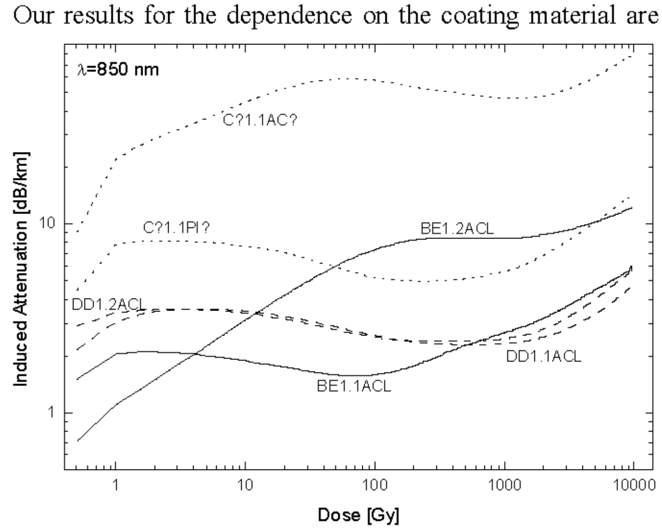

Fig. 2: Radiation-induced attenuation for selected fibers at 850 nm. Shown are the results of fibers manufactured by B and D with a different CCDR. Obvious is the high radiation sensitivity of the acrylate-coated fiber from C .

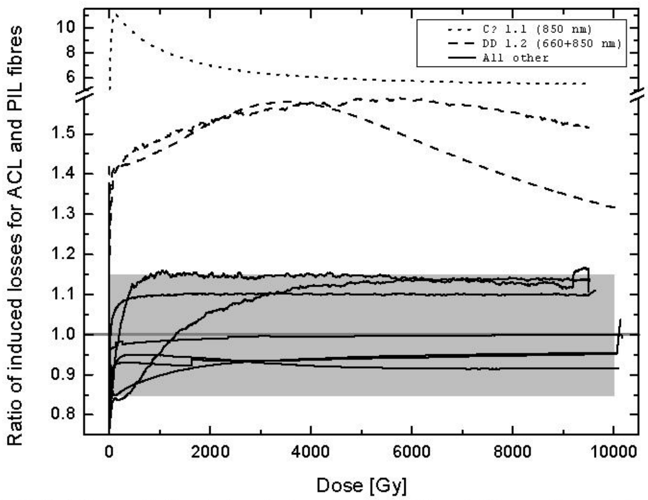

Fig. 3: Relative radiation-induced attenuation of different fibers with acrylate and polyimide coating which were drawn under identical conditions. The shaded area indicates a variation of 15% and means no significant change of the radiation effects with different coating material. Note the different scaling for top and bottom part of the graph.

shown in Fig. 3. The curves show the ratio of the induced attenuations versus the dose for fibers drawn from the same preform but applied with different coatings. For the products of manufacturer C the positive influence of the polyimide coating observed [6] is obvious. The induced losses are 6 to 10 times higher with the acrylate coating. But this is not the case for most of the other fibers. With the exception of the DD 1.2 fibers with a deviation of 40 % to 55 %, the ratio of the induced attenuation is between 85 % and 115 %. So the influence of the coating material for these fibers is below 15 % and cannot be regarded as significant. Only for two preforms the coating material itself or the method to apply it onto the fiber has an influence on the radiation sensitivity. For the other four preforms no significant influence was observed.

Since the absolute induced losses of the C? 1.1 fibers (see Fig. 2) also were much higher than those of the other samples, one could conclude that only for worse preform material a post-drawing annealing occurs. The fibers made of the best preforms did not show this dependency

C. Influence of cladding to core diameter ratio

In previous papers [5], [7] it was also reported that the radiation-induced attenuation increases with higher CCDR. A reason for this could be the longer time it takes to apply thicker layers of the cladding material during which a constant exposition to damaging UV light occurs. This should in consequence increase the radiation sensitivity which was discussed in more detail in [7].

Fig. 4 depicts the ratio of the induced losses at 660 nm and 850 nm for fibers produced under the same drawing conditions (drawing speed and coating material) but different CCDR by two manufacturers (D and B). The curves divide up into two groups, one for each manufacturer. The fibers with a higher CCDR (1.2) by manufacturer B show significantly higher induced attenuations than with a CCDR of 1.1. This is independent of the wavelength, drawing speed and coating material and consistent with the previously reported results. The samples produced by D on the other hand do not show such a clear dependence. In contrast to the B-fibers, fibers with a higher CCDR are superior.

This shows that general predictions of the radiation resistance of fibers with varying CCDR are not feasible. Due to the different processes involved in applying the cladding complete obverse results may be obtained.

D. Influence of core material manufacturer

To investigate the dependency on the core material, we investigated fibers made by company A using core materials from two different suppliers. The results in Fig. 5 indicate that the core material has an influence on the radiation resistance. Since both core materials are of high quality, the difference is only around 30% at lower dose values. The difference decreases for higher doses. It is not surprising that the radiation sensitivity depends on the core material since most of the light is guided through this material. The dose

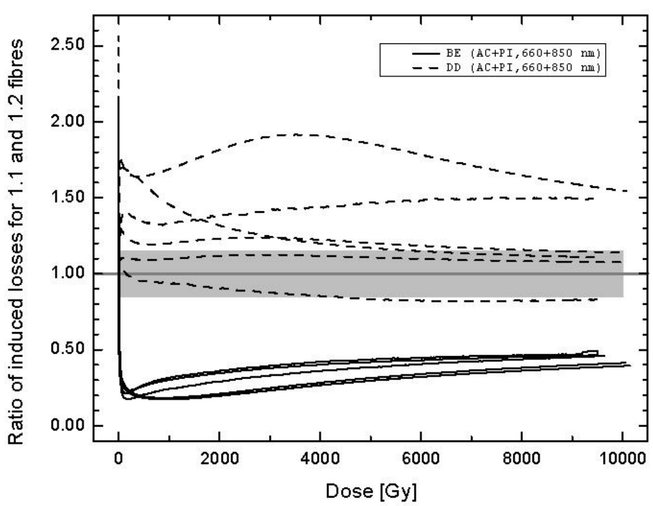

Fig. 4: Relative radiation-induced attenuation of fibers with a CCDR of 1.1 and 1.2. Again the shaded area indicates a ratio of 1.0 within 15%. Continuous lines represent samples of fibers drawn from preforms produced by manufacturer D and dashed lines symbolize manufacturer B.

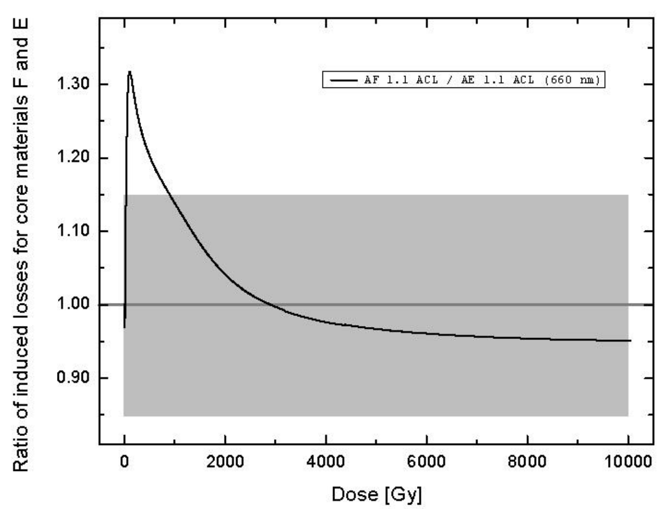

Fig. 5: Relative induced attenuation for two fibers drawn from preforms produced by the same manufacturer A using two different core materials supplied by F and E.

dependence indicates that the core material produced by F exhibits a fast radiation response which is not present for the core material from E.

IV. Conclusion

The dependencies of the radiation-induced attenuation in pure silica core fibers on coating material, CCDR, and core material have been presented. It was shown that the simple correlations proposed earlier [5],[6],[7] do not generally hold. For different manufacturers and therefore different production processes and parameters the influences may be different by up to a factor of 10 and even opposite to each other. So it seems very complex to predict the radiation behavior of a specific fiber and might be even impossible. Therefore individual sample testing is indispensable.

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