OPTICAL ABSORPTION OF NEUTRON-IRRADIATED SILICA FIBERS -- D. W. Cooke, E. H. Farnum and B. L. Bennett (Los Alamos National Laboratory)

SUMMARY

Induced-loss spectra of silica-based optical fibers exposed to high (10^{23} n-m^{-2}) and low (10^{21} n-m^{-2}) fluences of neutrons at the Los Alamos Spallation Radiation Effects Facility (LASREF) have been measured. Two types of fibers consisting of a pure fused silica core with fluorine-doped (~ 4 mole %) cladding were obtained from Fiberguide Industries and used in the as-received condition. Anhydroguide™ and superguide™ fibers contained less than 1 ppm, and 600 to 800 ppm of OH, respectively. The data suggest that presently available silica fibers can be used in plasma diagnostics, but the choice and suitability depends upon the spectral region of interest. Low-OH content fibers can be used for diagnostic purposes in the interval ~ 800 to 1400 nm if the exposure is to high-fluence neutrons. For low-fluence neutron exposures, the low-OH content fibers are best suited for use in the interval ~ 800 to 2000 nm, and the high-OH content fibers are the choice for the interval ~ 400 to 800 nm.

PROGRESS AND STATUS

The fibers were irradiated at LASREF over a two and one-half month period and subjected to either a low or high fluence environment. We have previously reported optical absorption in the spectral region 190 to 800 nm from high fluence-exposed fibers[1]. The low fluence region is characterized by neutrons with 97.8% having energy less than 0.1 MeV; there is only minimal gamma component in this region due to shielding. We now report optical absorption of silica fibers exposed to the low fluence neutron environment. The previous work was done in the interval 200 - 800 nm; we now extend the range to cover 200 - 2000 nm and measure the radiation-induced optical attenuation for fibers exposed to both low and high fluence environments.

Figure 1 shows the optical absorption spectrum of anhydroguide silica fibers exposed to high and low fluence neutron environments and compares it with absorption of an unirradiated sample. In the visible part of the spectrum we measure less than 50 dB/km attenuation in the virgin sample. Prior to the onset of band-edge absorption, there is a peak near 300 nm, which may be due to the fiber drawing process[2] or to the presence of chlorine.[3] Of interest is the significant radiation-induced absorption for both low and high fluence-exposed fibers. Although not shown, we measured attenuation up to 10^4 dB/km in the high fluence fiber for wavelengths below about 800 nm. The low fluence fiber exhibits a peak near 630 nm, which is attributed to the well-known radiation-induced nonbridging oxygen hole center.[4] Near 400 nm the attenuation has increased to 10^4 dB/km. We also observe an attenuation peak near 1400 nm for both low and high fluence-exposed fibers and attribute it to an overtone vibration mode of the 2750 and 2830 OH fundamental band.

Shown in Fig. 2 are the attenuation spectra for superguide silica fibers exposed to both low and fluence environments. For comparative purposes we also show the attenuation for a virgin specimen. Again, the pristine sample exhibits a weak peak near 300 nm with less than 50 dB/km attenuation in the region 400 to 800 nm. However, there is significant attenuation for all fibers above 800 nm. Three peaks near 950, 1250 and 1400 nm are all due to combination and overtone bands of the OH fundamental mode.[2] This is expected because of the high OH content (600 to 800 ppm) of the superguide fiber compared to the low OH content (< 1 ppm) of the anhydroguide specimen. This assignment of the combination and overtone modes is further substantiated by the fact that the intensities of these three peaks are not affected by radiation. This is not the case however for a peak observed near 1900 nm. As shown in Fig. 2, this particular peak grows with radiation exposure and its origin is presently unknown.

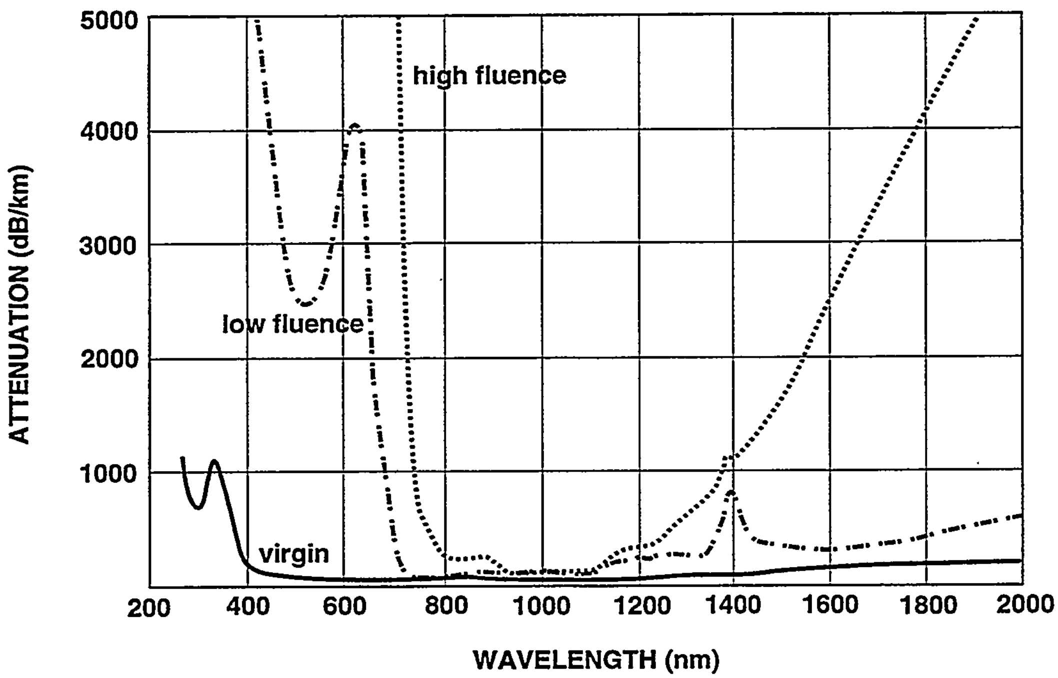

Fig 1. Optical attenuation of anhydroguide™ fibers exposed to low and high fluence neutron environments. The attenuation of a virgin specimen is shown for comparative purposes.

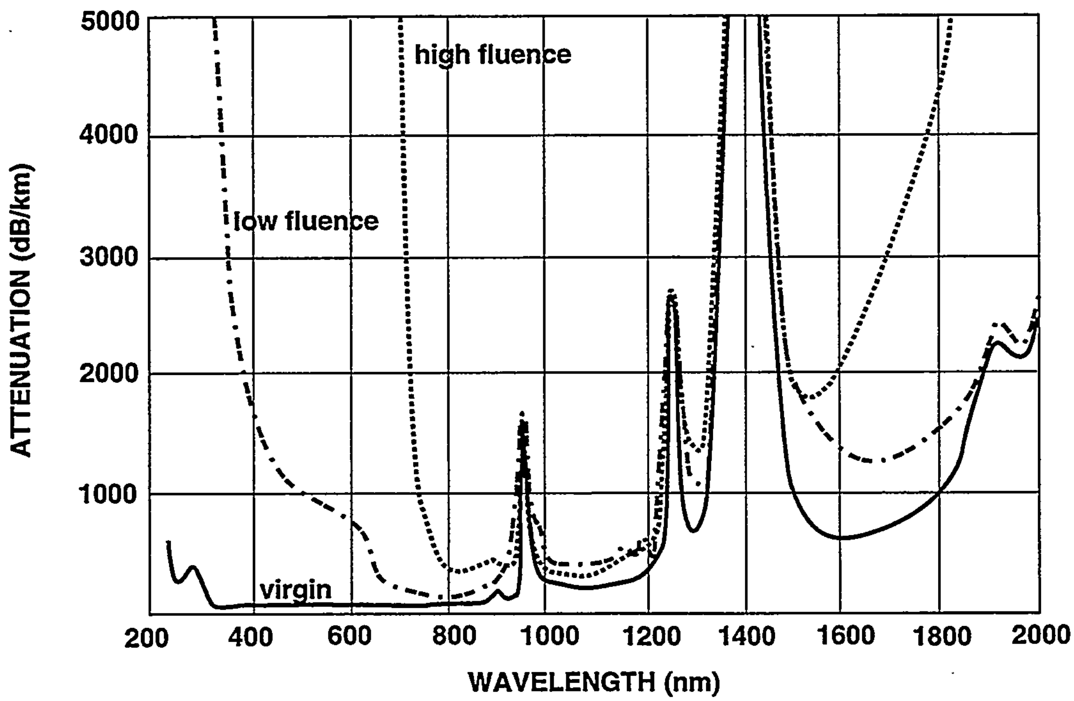

Fig. 2. Optical attenuation of superguide™ fibers exposed to low and high fluence neutron environments. The attenuation of a virgin specimen is shown for comparative purposes.

Figure 2 also shows the relative growth of non-bridging oxygen hole and short wavelength (< 400 nm) centers (usually attributed to E'-type defects). For the low fluence exposure it is easy to discern the non-bridging oxygen hole center peak near 630 nm as it grows with exposure. However, for high fluence exposures the attenuation is so large as to preclude observation of individual peaks below about 700 nm.

From a comparison of the attenuation data obtained on superguide™ and anhydroguide™ fibers exposed to high and low fluence neutron environments, we see that the low-OH anhydroguide™ fibers are more radiation resistant and, therefore, are the current material of choice for ITER applications. However, it is also evident that low OH fibers are susceptible to radiation damage in the visible portion of the spectrum even when subjected to low fluence neutron environments. This will obviously limit their usefulness in ITER diagnostic applications.

Although not exposed to neutrons, we show for comparative purposes in Fig. 3 the optical attenuation of two pristine Russian fibers possessing both low and high OH content. These were obtained from the Fiber Optics Research Center of the Russian Academy of Sciences through D. L. Griscom. The low-OH specimen is comprised of a KS-4V silica core and contains < 200 ppb OH and < 20 ppm chloride. The fiber labeled high OH in Fig. 3 has a KU silica core and contains 800 - 900 ppm OH.

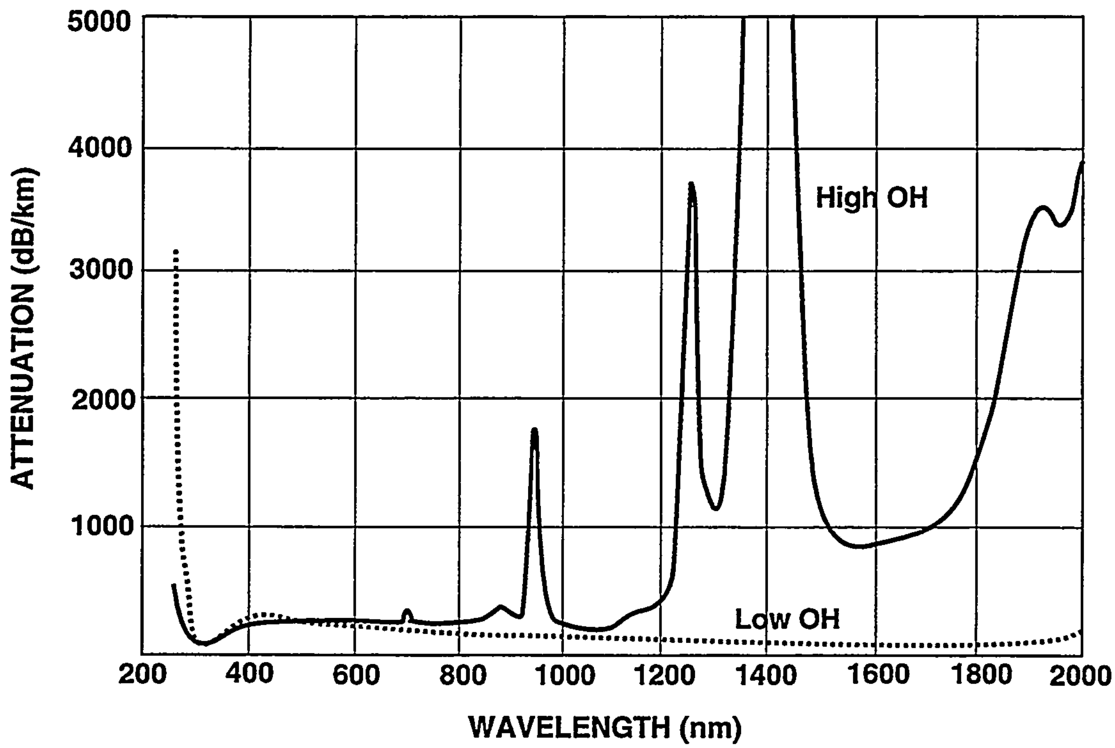

Fig. 3. Optical attenuation of unirradiated low- and high-OH content silica fibers obtained from Russia.

Consistent with the stated low OH content, there is no measurable attenuation due to OH stretching modes of this fiber. There is, however, a peak of unknown origin near 400 nm. The radiation resistance of this fiber to neutrons has not been examined; however, D. L. Griscom has measured the gamma-induced attenuation and found significant sensitivity in the visible spectrum.[5]

Finally, we attempted radioluminescence measurements on low-fluence-exposed fibers, but were unsuccessful because of the extreme brittleness of the nylon jackets. In a typical experiment we prepare a bundle of 4 - 5 fibers with polished ends for the measurement. Because of the radiation-induced brittleness of the nylon jackets on each fiber, we were unable to polish the ends, which precluded any radioluminescence measurement. The nylon jackets apparently are very radiation sensitive and become darkened upon exposure even to a low fluence neutron environment; this may limit their use in ITER diagnostic applications.

CONCLUSIONS

We have measured the optical attenuation of pristine and neutron-irradiated, low- and high-OH content silica fibers in the wavelength interval 250 to 2000 nm. The low-OH content fibers are devoid of the intrinsic absorption associated with combination and overtone modes of the OH molecule and exhibit minimal attenuation over the entire region investigated. Exposure to high fluence neutrons induces strong absorption of the well-known defects (E' type, peroxy radical and nonbridging oxygen hole center), in addition to band-like absorption above ~ 1400 nm. Overall, the useful optical window is ~ 800 to 1400 nm and exists only in the low-OH specimen, making these fibers not particularly well suited for diagnostic use near the fusion plasma, and certainly not useable in the visible region.

Fibers exposed to low-fluence neutrons suffer radiation-induced attenuation similar to that observed from high fluence exposure, but with the attenuation reduced in magnitude. For diagnostic use in the visible portion of the spectrum, the high-OH content fibers exhibit less attenuation than the low content counterpart and are preferred. Their intrinsic OH absorption at longer wavelengths, however, makes them less attractive for diagnostic use above ~ 800 nm than the low-OH fibers.

The data suggest that presently available silica fibers can be used in plasma diagnostics, but the choice and suitability depends upon the spectral region of interest. Low-OH content fibers can be used for diagnostic purposes in the interval ~ 800 to 1400 nm if the exposure is to high fluence neutrons. For low fluence neutron exposures, the low-OH content fibers are best suited for use in the interval ~ 800 to 2000 nm, and the high-OH content fibers are the choice for the interval ~ 400 to 800 nm. Strong absorption of all fibers below ~ 400 nm will likely preclude their use in this spectral region unless other mechanisms (heating during irradiation, thermal or optical quenching, etc.) can be found to mitigate the radiation-induced damage.

REFERENCES

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