OPTICAL PROPERTIES OF SILICA FIBERS AND LAYERED DIELECTRIC MIRRORS -- D. W. Cooke, E. H. Farnum, F. W. Clinard, Jr., B. L. Bennett (Los Alamos National Laboratory) and A. M. Portis (UC-Berkeley)

SUMMARY

Radioluminescence (RL) from virgin and neutron-irradiated (10^{23} n-m^{-2}) silica fibers has been measured in the temperature interval 4 to 300 K. Unirradiated specimens exhibit a *decrease* in RL intensity with increasing temperature such that the intensity is extremely weak at room temperature. The luminescence is well described by a barrier-limited exciton mechanism. In contrast, the heavily-irradiated samples show an *increase* in RL with elevated temperatures such that the intensity at room temperature is about twice that measured at 4 K. Neutron irradiation presumably produces many luminescence centers that act as radiative sites for exciton decay. Absolute specular reflectance of a series of neutron-irradiated, layered dielectric mirrors was also measured. In addition to structural damage that has already been reported, we typically found approximately 10% reduction in the reflectance following irradiation. These results suggest that neither fibers nor dielectric mirrors are well suited for use near the high radiation area of the ITER plasma.

PROGRESS AND STATUS

Radioluminescence

The use of optical fibers for transmitting diagnostic information on ITER plasma performance is anticipated,[1] and the general consensus is that pure-silica-core/F-doped silica clad fibers are the best candidate materials.[2] However, they are not ideal because they suffer from radiation-induced luminescence (radioluminescence) and attenuation, which complicates measurement of the diagnostic signal.[3] Furthermore, at high γ-flux levels scattered electrons act to produce Cerenkov radiation in the silica fibers thus contributing additional unwanted emission.[4] As part of our ongoing research into the radioluminescence (RL) of silica fibers,[5] we have investigated silica-core/F-doped clad fibers containing low OH (< 1 ppm) as manufactured by Fiberguide Industries, Inc. (the material is referred to commercially as anhydroguide™). A comparison is made of the RL from unirradiated and heavily neutron-irradiated (10^{23} n-m^{-2}) specimens in the temperature interval 4 to 300 K. We also investigated RL from the core material, core+cladding, and fiber separately to see if any differences resulted from fiber processing.

In unirradiated specimens of anhydroguide (core, core+cladding, and fiber) we generally found principal emission near 500 nm. Weaker band emission is also seen near 670 nm as previously reported.[5] From a Gaussian fit of the RL data taken under continuous x-ray exposure (E_{eff}= 25 keV) as a function of temperature we conclude that the principal emission is due to recombination of self-trapped excitons.[6] It is important to note that samples are exposed only during a 15-s interval at each temperature of interest. As shown in Fig. 1, the RL decreases as temperature increases such that at room temperature we cannot resolve the main emission band. The solid circles of Fig. 1 are RL data and the solid line is a fit to Eq. (1) of the temperature dependence based upon our assumption that the reduction in RL intensity arises from quenching of self-trapped exciton luminescence by nonradiative recombination. Assuming a polynomial distribution of exciton barrier energies, a straightforward analysis leads to an equation describing RL as a function of temperature:

$$L_s(T) \approx L_s(0)e^{-T/T_s} = \frac{L_s(0)}{1+(T/T_s)+(1/2)(T/T_s)^2+\cdots(1/n!)(T/T_s)^n+\cdots} \qquad (1)$$

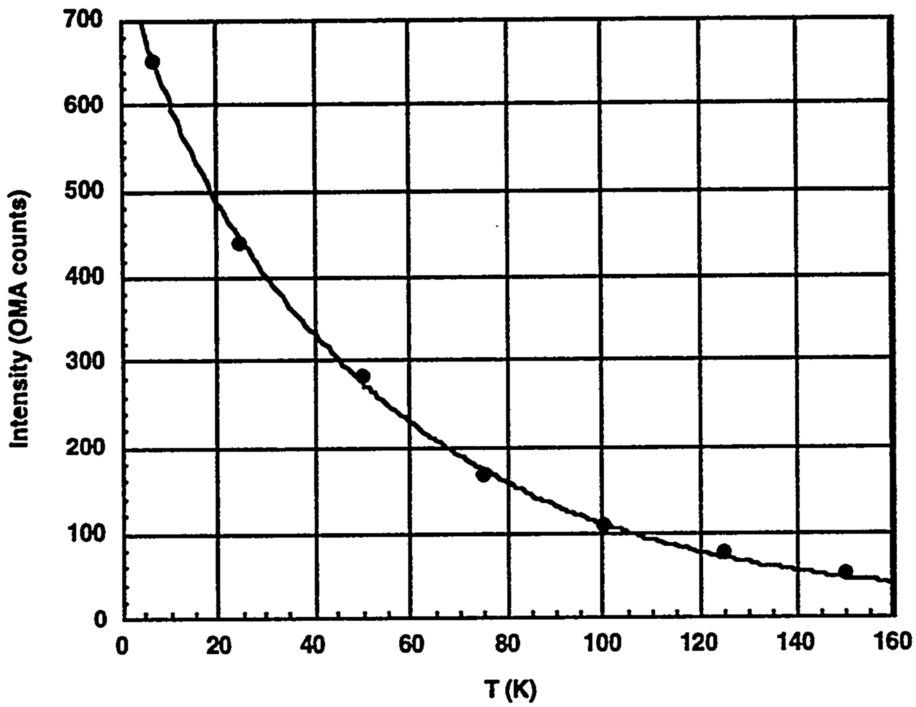

Fig. 1. Temperature dependence of RL from unirradiated anhydroguide. Solid circles are experimental data and the solid line is a fit to Eq. (1). Error bars are smaller than the plot symbols.

Temperature dependence of RL from neutron-irradiated (10^{23} n-m^{-2}) fibers is shown in Fig. 2. First we note that the general trend is an *increase* in intensity as temperature increases, quite unlike the well-behaved *decrease* observed in the unirradiated fibers. Secondly, there is considerable error in the fitting of the spectra to a Gaussian form. Presumably this is due to the plethora of radiation-induced defects that now provide a broad array of recombination sites. Although we do not understand the details of radiation damage suffered by this sample, it is obvious that many sites now exist for exciton recombination as compared to the pristine specimen.

For ITER diagnostic applications the data suggest that RL will indeed be a problem at some level of total dose. Unfortunately we have data only for the two extreme cases, unirradiated and heavily irradiated. It is plausible that some intermediate dose may be acceptable for diagnostic purposes. Nevertheless, the data suggest that RL from silica fibers subjected to heavy neutron doses must be taken into account when used in diagnostic applications. This luminescence is in addition to the Cerenkov radiation that is expected to also interfere with transmission of diagnostic signals. It is important to note that a direct comparison of the intensities given in Figs. 1 and 2 cannot be made because of variations in quality of optical coupling and sample size. However, we note that the weakest signal from the irradiated specimen (Fig. 2) is easily detected and is greater than the weakest signal from the unirradiated sample (Fig. 1). The trends of the data shown in Figs. 1 and 2 are correct and clearly illuminate the problem of RL in heavily irradiated fibers. Further work on RL of neutron-irradiated fibers will be required to quantify the signals and to assess their dependence on total dose.

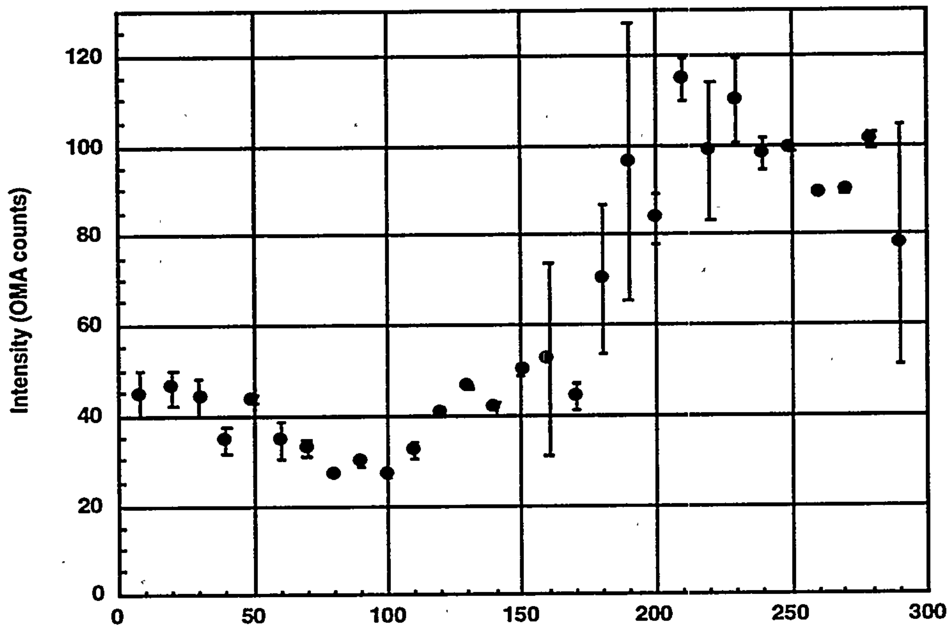

Fig. 2. Temperature dependence of RL from neutron-irradiated anhydroguide.

Neutron-Irradiated Mirrors

A series of multilayered synthetic mirrors, designed for use in the visible/near infrared region, were exposed to a fast neutron fluence of 10^{23} n-m^{-2} near 300°C. Characteristics of these mirrors along with a description of the physical damage incurred due to the neutron exposure has been previously described.[7] Briefly, these mirrors are composed of alternating layers of either HfO_2, ZrO_2, or TiO_2 with SiO_2 deposited onto SiO_2 substrates. The purpose of the high-Z material is to reflect the incident radiation while the low-Z material acts to tune the reflectance to specific wavelengths. Four mirrors and one plate polarizer investigated. The number of bilayers, with comments on the appearance of each after irradiation, are given below:

HfO_2/SiO_2, 37 bilayers – slight crazing
ZrO_2/SiO_2, 121 bilayers – coating almost totally flaked off
ZrO_2/SiO_2, 29 bilayers – moderate crazing and chipping
TiO_2/SiO_2, 39 bilayers – no discernible damage
TiO_2/SiO_2, 39 bilayers (plate polarizer) – no discernible damage

Absolute spectral reflectance measurements on each mirror and plate polarizer were made at room temperature with a specially-equipped Cary 5E spectrophotometer. All measurements were made at an incident angle of 7°and the results are shown in Fig. 3. Unfortunately, pre-irradiation measurements were not made; therefore, direct comparison is not possible. However, data obtained from the manufacturer[8] on similar materials indicate that reflectivity at designated wavelengths is greater than 90%. Mirrors were designed for optimal reflectivity at the following wavelengths; refer to Fig. 3: (a) 248 nm, (b) 400-700 nm, (c) 511 nm, (d) 694 nm, and (e) 1064 nm. In each case there is at least a 10% reduction in reflectance following neutron irradiation. Fig. 3(b) does not represent a reliable measurement because the coating was almost totally flaked off this particular mirror. The cause(s) for reduced reflectivity is not understood at present although it has been suggested[7] that differential swelling between substrates and their layered structures could be a source of physical damage that could also affect the overall reflectivity.

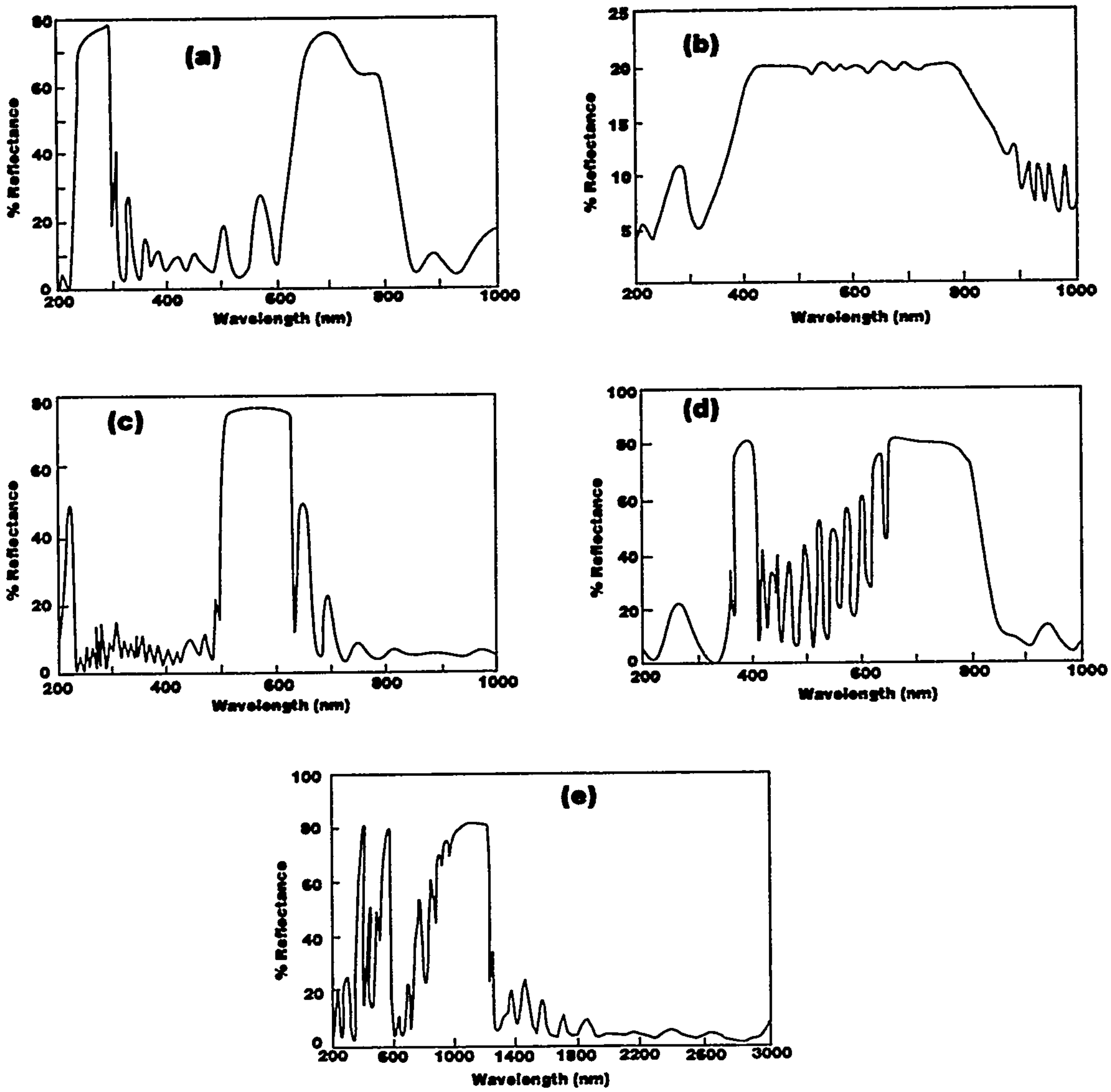

Fig. 3. Absolute specular reflectance of neutron-irradiated mirrors. (a) HfO_2/SiO_2 - 37, (b) ZrO_2/SiO_2 - 121, (c) ZrO_2/SiO_2 - 29, (d) TiO_2/SiO_2 - 39, and (e) TiO_2/SiO_2 - 39.

CONCLUSIONS

Our results suggest that RL from heavily-irradiated silica fibers will be significant at the temperatures anticipated for ITER operation. This emission, in addition to Cerenkov radiation, will certainly interfere with the transmission of ITER diagnostic signals via optical fibers. Dielectric mirrors suffer at least a 10% reduction in reflectivity as a result of high-fluence (10^{23} n-m^{-2}) neutron irradiation and will not likely be good candidates for use in the high-fluence regions of ITER.

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