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In situ transmissivity measurements of KU1 quartz in the UV range under 14 MeV neutron irradiation

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Abstract

The transmissivity of KU-1 quartz which is a candidate of the window material for UV and visible spectroscopy in ITER was measured under the irradiation of 14 MeV neutrons up to the fluence of 7.4×10^{19} n/m^2 in the UV range (200–400 nm). Significant transmission loss was observed in the wavelength range of 200–300 nm. Two absorption peaks were identified: an E′-center at 215 nm and Si(III) defects at 245 nm. The E′-center absorption is much larger than the Si(III) defect absorption. The transmission loss increased with the neutron fluence, decreased during the irradiation breaks and returned almost to the same level as before when the irradiation resumed. This phenomenon indicates that an absorption induced by the neutron irradiation is caused by stable scattering and short lifetime centers.

1. Introduction

UV range spectroscopy is one of the most important diagnostics for impurity monitoring in International Thermonuclear Experimental Reactor (ITER). The diagnostic windows will be irradiated by neutrons and gamma-rays during operation. It is necessary to get the transmissivities of the windows for spectroscopic measurements just during irradiation. There are few data of in situ neutron irradiation effects on the window material in the UV range. We have carried out the irradiation test on KU-1 quartz [1], which is a radiation-hardened fused quartz with a high OH concentration of 800 ppm and a candidate of the window material for UV and visible spectroscopy in ITER, using the 14 MeV neutron facility fusion neutronics source (FNS) in JAERI Tokai [2].

The objective of this irradiation test is to measure the transmission loss of KU-1 quartz during neutron irradiation and to compare the data with those during the breaks between irradiations in the wavelength range from 200 to 400 nm.

2. Material and test methods

The KU-1 sample, which was 16 mm in diameter and 8 mm in thickness, was mounted in a sample changer arm and was located in front of the rotating tritium target of the FNS as shown in Fig. 1. The distance between the center of the sample and the tritium target was 22 mm. The energy of the neutrons was 14 MeV. UV light from a D_2 lamp was collimated by a fused quartz lens located about 20 cm far from the target and illuminated the sample. The transmitted light was focused at the end of the optical fiber by a fused quartz lens and guided to a spectrometer located behind a heavy concrete shielding wall with a 1.8 m thickness. The core of the optical fiber was made of fused quartz and was 400 μm in diameter. The spectral intensity distribution of the

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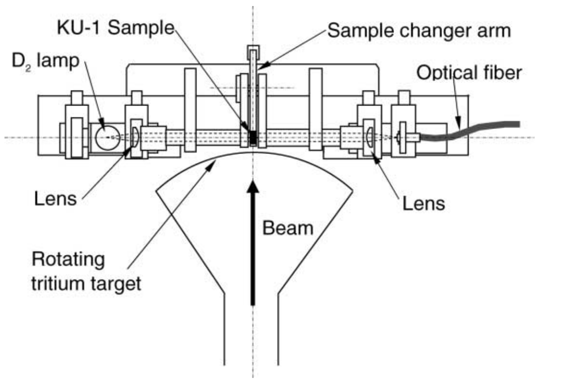

Fig. 1. Optical system for the in situ transmissivity measurement of KU-1 quartz in the UV range of FNS.

transmitted light was measured by the spectrometer with a wavelength resolution of 1.4 nm. In order to estimate the intensity drop of the D_2 lamp and the increase of transmission losses of the lenses and fiber optics under neutron irradiation, the spectral intensity distributions of the transmitted light were measured by removing the KU-1 sample from the optical beam line for each measurement. The transmissivity of the KU-1 sample was derived from the ratio of the spectral intensity distribution with and without the KU-1 sample on the optical beam line.

The radiation-induced loss of the optical fiber was so significant in the UV range that we replaced the fiber every week during the experiment, which took three weeks. The total fluence at the center of the sample was measured to be 7.4×10^{19} n/m^2 by activation foils of niobium attached to the target and to another side of the sample. In this measurement, the ^{93}Nb(n,2n)^{92m}Nb reaction with a half-lifetime of 10.15 days was used. The flux was estimated to be around 3×10^{14} n/m^2 s. The ionization dose rate was evaluated by calculations using the neutron Monte Carlo code MCNP-4B [3] to be 0.66 Gy/s by neutrons and 0.034 Gy/s by photons for quartz. The gamma-ray contribution is less than 5% of the total ionization dose.

3. Results

Fig. 2 shows the optical densities OD(λ) (cm^{-1}), calculated by the equation of $\log(1/T(\lambda))/(0.8\ \text{cm})$, as a function of the wavelength λ from 200 to 400 nm during the neutron irradiation for different fluences. Here, $T(\lambda)$ is the measured transmissivity at the wavelength λ and 0.8 cm is the thickness of the KU-1 sample. There was almost no increase of the optical density, which is the indicator of the transmission loss, in the wavelength range longer than 350 nm. The optical density increased significantly with the neutron fluence in the wavelength range of 200–300 nm. Two absorption peaks were identified: an E′-center at 215 nm and Si(III) defects at 245 nm. The E′-center absorption is much larger than the Si(III) defect absorption. The optical densities at 235, 245, 260 and 280 nm plotted against the neutron fluence are shown in Fig. 3. The plotted points indicated at A–F are optical densities during the irradiation breaks at the given fluences. The optical densities increased linearly with the neutron fluence. The increase rates for the fluence over 3.8×10^{19} n/m^2 were larger than those for the lower fluence. The optical densities decreased during each irradiation break. When the irradiation was resumed after each break, the optical densities returned

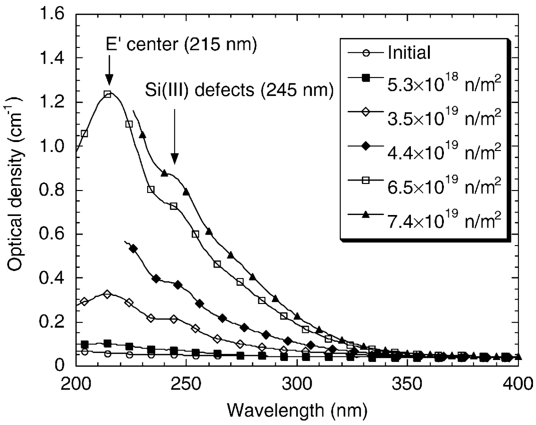

Fig. 2. Optical densities as a function of the wavelength (200–400 nm) before and during neutron irradiation for different fluences.

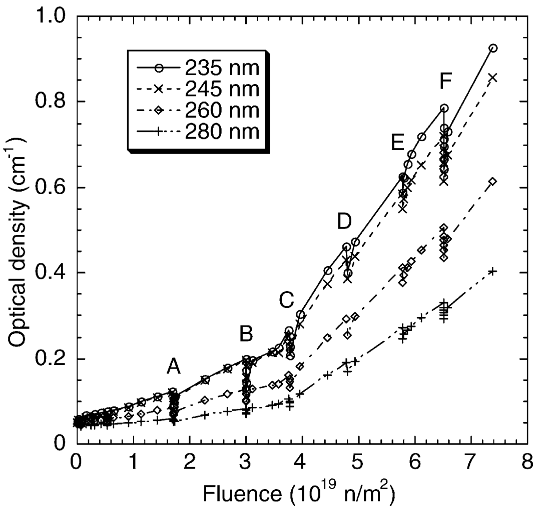

Fig. 3. Optical densities at 235, 245, 260 and 280 nm as a function of the neutron fluence. The plotted points indicated at A–F are optical densities during the irradiation breaks corresponded to the fluences.

almost to the same level as just before the break. Fig. 4 shows the optical densities as a function of the wavelength during the irradiation at fluences of 3.8 and 6.5×10^{19} n/m^2 and after 770 and 810 min from the start of the irradiation breaks C and F, respectively. Fig. 5 shows the normalized optical densities as a function of time from the start of the irradiation break F (after the fluence of 6.5×10^{19} n/m^2) for different wavelengths. The optical density recovered by about 15% after 150 min at 215 nm in this case. The recovery times for different wavelengths were almost the same. Fig. 6 shows the optical densities as a function of time for break A, C and F at 235 nm. From this figure, the recovery time of the optical density after larger irradiation fluences is longer than after minor fluences. This tendency was the same for other wavelengths.

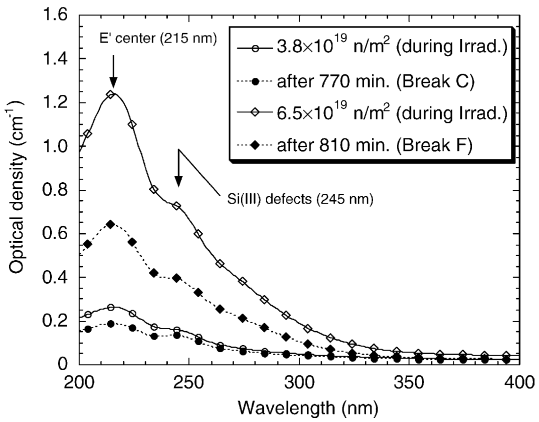

Fig. 4. Optical densities as a function of the wavelength during the irradiation at fluences of 3.8 and 6.5×10^{19} n/m^2 and after 770 and 810 min from the start of irradiation breaks C and F, respectively.

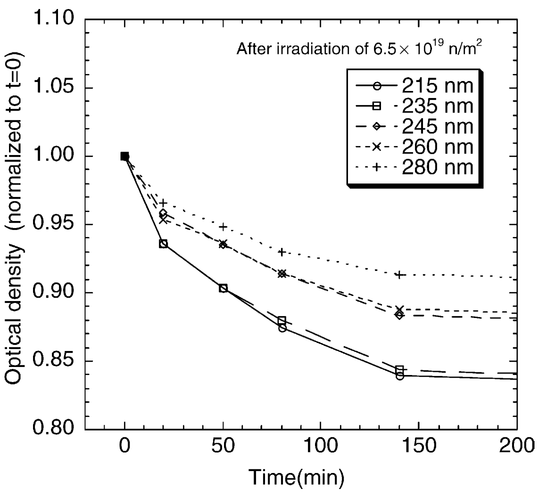

Fig. 5. Normalized optical densities as a function of time from the start of the irradiation break F (after the fluence of 6.5×10^{19} n/m^2) for different wavelengths.

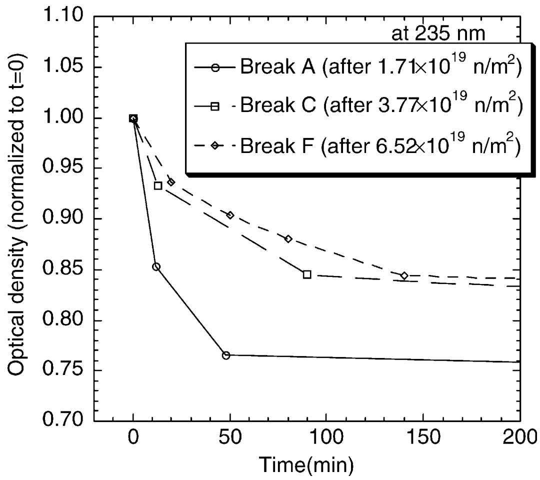

Fig. 6. Optical densities as a function of time from the start of the irradiation breaks A, C and F at 235 nm.

The same in situ measurement was carried out under ^{60}Co gamma-ray irradiation (dose rate: 1.16×10^4 Gy/h). No clear relaxation of the optical density was observed during the breaks.

4. Discussion

As described above, the optical density, as an indicator of absorption, decreased during the irradiation breaks and returned almost to the same level as just before the breaks. This phenomenon indicates that an absorption induced by the neutron irradiation is caused by accumulated defect and short lifetime centers. The first contribution is proportional to the neutron fluence and the latter is almost proportional to the neutron flux.

Apparently the spectroscopic method will be able to carry out measurements on the KU-1 quartz windows in the wavelength range longer than 300 nm in ITER, but it will be necessary to prevent the neutron fluence above 1×10^{19} n/m^2 in the wavelength range shorter than 250 nm. The absorption decreased during the breaks between irradiation and returned almost to the same level as just before the breaks when the irradiation resumed. Therefore, the calibration of the optical diagnostics systems will be necessary during the plasma discharges by neutron irradiation. If it is impossible, the transmissivity of the window during neutron irradiation should be estimated from the data measured during the breaks between the plasma discharges.

5. Conclusion

The transmission losses of KU-1 quartz were measured during the 14 MeV neutron irradiation with a fluence up to 7.4×10^{19} n/m^2 and were compared with those during the breaks between the irradiations in the wavelength range of 200–400 nm. The data will be useful for designing the diagnostics windows in ITER especially for UV spectroscopy. The data have been measured at room temperature. It will be necessary to confirm the absorption of KU-1 quartz in the temperature range of 100–200 °C, which is expected during ITER operation.

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