Radiation Hardness Study on Fused Silica

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Abstract

Radiation hardness tests have been carried out on fused silica samples of the highest optical grade from three different manufacturers (Suprasil, Lithosil and Corning). The samples were irradiated with protons in order to emulate the expected accumulated radiation damage over the entire life span of the future PANDA experiment. Changes in optical properties were the primary focus of this study. The optical transmission over a broad wavelength band ranging from UV to visible light was investigated using a commercial spectrophotometer. In addition, changes of the super polished surface were studied using an interferometer.

Key words: Fused Silica, Radiation Hardness, Optical Transmission
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1. Introduction

The PANDA experiment [1] at FAIR will be a fixed target experiment using up to 15 GeV/c beam of anti-protons which will allow QCD studies with unprecedented precision. Two Cherenkov detectors based on the DIRC principle are foreseen: a barrel DIRC [2,3] covering the central part of the target spectrometer of PANDA and a disc DIRC [2,4] in the forward endcap region of the target spectrometer. Fused silica is the natural choice as radiator material for a DIRC, given its optical properties and radiation hardness. Nevertheless, the harsh radiation environment in the PANDA detector, especially in the forward direction, will be a challenge for any material.

2. Irradiation Set-up

Fused silica samples of the highest optical grade from three different manufacturers were used in this study: Corning 7980, Schott Lithosil Q0 and Heraeus Suprasil 1. All samples were super polished and the surface flatness was specified to be better than 65 nm over the entire surface. The dimensions of the Suprasil and Lithosil samples were $50\times50\times15\,\mathrm{mm}^3$, whereas for the Corning sample

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Table 1
Overview of fused silica samples used in irradiation test.

Manufacturer	Type	Dimensions
Corning	7980	$80\times80\times20\,\mathrm{mm}^3$
Heraeus	Suprasil 1	$50\times50\times15\,\mathrm{mm}^3$
Schott	Lithosil Q0	$50\times50\times15\,\mathrm{mm}^3$

were $80\times80\times20\,\mathrm{mm}^3$. In addition to the fused silica samples, several types of crown glass were included in this irradiation test. All samples were mounted in specially designed light-tight frames.

The irradiation was carried out at KVI in Groningen, Netherlands, using a proton beam extracted from KVI's cyclotron with an energy of 150 MeV. The beam passed through 0.4 mm aluminium scatter foil and, 45 cm downstream, a collimator with an aperture of 5 mm and a thickness of 45 mm before impinging on the samples. The distance between the collimator and the samples was 13 cm. The beam intensity was monitored by an ionisation chamber placed behind the collimator. The beam intensity distribution was determined using a LANEX scintillating screen and a CCD camera. A full-width half-maximum size of 4 mm was measured. The samples were mounted on a remote controlled moving table allowing irradiation of different spots on each sample. Each radiation spot is separated by approx. 25 mm from its adjacent spot as shown in fig. 1.

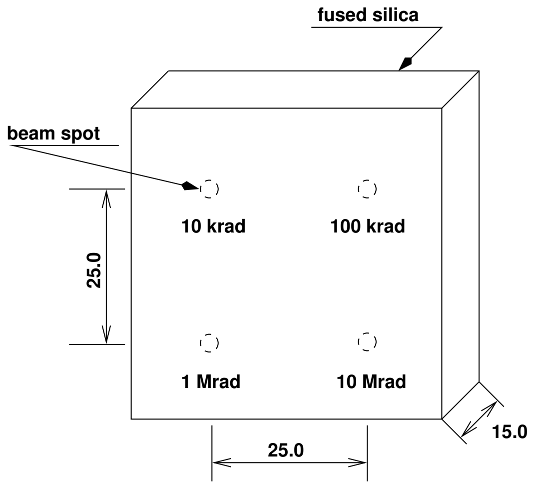

Fig. 1. Schematic drawing of intended dose distribution across a sample tile.

The estimated total radiation dose for the disc DIRC over its lifetime in the PANDA experiment is 100 krad. Four different dose levels (10 krad, 100 krad, 1 Mrad and 10 Mrad) were chosen to account for possible inaccuracies in this estimate. The beam current was adjusted to the envisaged dose such that a dose of 10 Mrad was delivered in approx. 6 minutes. After the irradiation run the samples had to be kept at KVI for four weeks in order to reach radiation levels acceptable for commercial transport.

Only after unpacking of the crown glass samples were problems with the beam position during the 10 krad run discovered. Instead of a disc-shaped irradiation spot a broad, elongated band towards the edge of the tiles was visible for all crown glass samples. An estimate for the true accumulated dose for this run is not possible and the results were discarded. However, the other runs at higher dose levels were not affected.

3. Optical Characterisation

The optical transmission of the fused silica samples was measured with a Varian Cary 300 spectrophotometer. The Cary 300, covering the spectral range from 200 – 800 nm, utilises a double-beam setup. An additional solid sample holder was installed in the sample compartment to ensure an orthogonal and repeatable sample alignment with respect to the sample beam. The spectrometer beam spot size at the sample position was measured to be 2 mm horizontally and 8 mm vertically. The repeatability of results across the sample surface was estimated by measuring 4 spots prior to irradiation. The obtainable precision is estimated to $\pm\,0.4\%$ absolute transmission. The spots were chosen to closely match the planned irradiation spots. Fig. 2 shows the averaged transmission of the Suprasil 1 sample prior to irradiation.

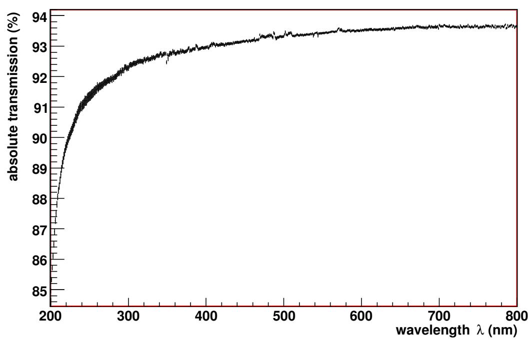

Fig. 2. Average wavelength dependent transmission for Suprasil 1. Transmission values were not corrected for Fresnel losses. The error bars display the statistical fluctuations only, no systematic effects were included.

Crown glass samples, irradiated in the same experiment and which showed significant radiation damage for all dose levels, were used to align the samples with respect to the sample beam in order to scan across the irradiated spots. Each sample was scanned across the wide surface in steps of 2 mm. The stepsize is governed by the spectrophotometer's beam spot size. The transmission measured after irradiation was compared to the reference measurement. The result is given as normalised transmission difference ΔT_{norm}:

$$\Delta T_{norm} = \frac{T_{before} - T_{after}}{T_{before}} \quad ,$$

which is used to account for Fresnel losses occuring at the surfaces of the samples. ΔT_{norm} thus describes the change of transmission due to absorption changes inside the bulk material. The uncertainty of ΔT is better than $\pm$ 1% absolute transmission.

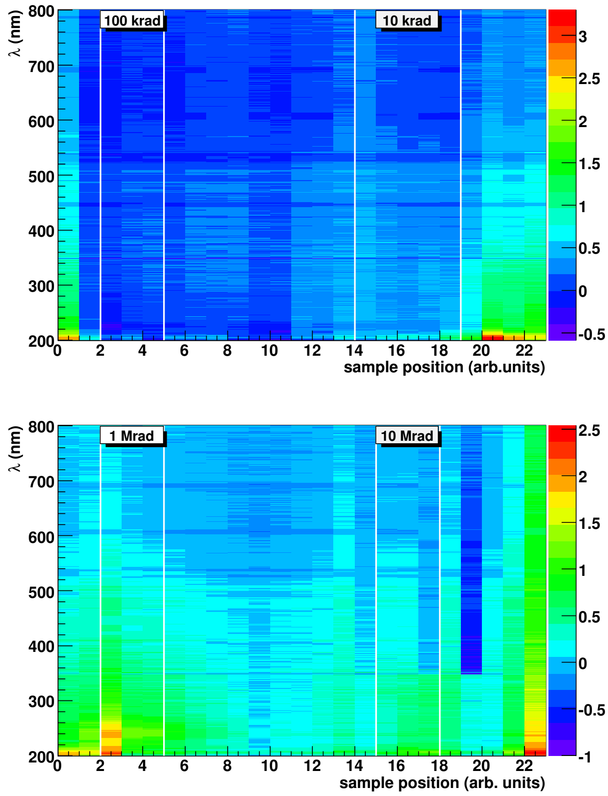

Fig. 3. Normalised transmission difference ΔT_{norm} for Heraeus Suprasil 1. The vertical lines indicate the expected position of the radiation spots. No distinct features corresponding to the irradiation spots are observed within the obtained precision. Large deviations at the corners are attributed to edge effects.

No degradation of transmittance was found for all three fused silica samples tested. Results for Heraeus Suprasil 1 are shown for example in fig. 3, the other samples show similar results. None of the samples exhibits any significant radiation damage. Large deviations at the corners are attributed to edge effects. The peculiar difference at the 1 Mrad spot in fig. 3 is thought to be caused by surface contamination, especially since the 10 Mrad spot does not show any degradation. Previous studies on Suprasil Standard [5], by contrast, found a signficant transmission reduction in the UV region after irradiation with a dose of 280 krad. Despite the fact that we used a different sample geometry, the results from [5] suggest that we should have observed a significant deterioration in our sample.

Compactification under irradiation has been observed for fused silica [6]. The super polished surfaces of the three samples under investigation were measured using a Zygo XP/D interferometer, see fig. 4. This interferometer is capable of measuring the surface roughness down to 0.2 nm. The surface facing towards the beam was measured again for each sample after irradiation. No distinct structures corresponding to the four impact points of the proton beam could be identified on any sample, cf. fig. 5. The two visible spikes were attributed to an imperfect coating of the sample's rear side which is neccessary to suppress interfering reflections.

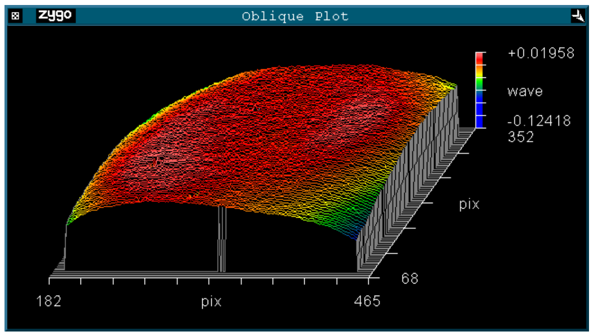

Fig. 4. Surface map of Suprasil 1 sample obtained with Zygo XP/D interferometer prior to irradiation. Overall surface flatness was within specifications. Sagging edges caused by the polishing method were observed [7].

4. Conclusions

The radiation hardness of three different fused silica types of the highest optical grade were studied. Each sample was irradiated with a 150 MeV proton beam at four different dose levels (10 krad, 100 krad,

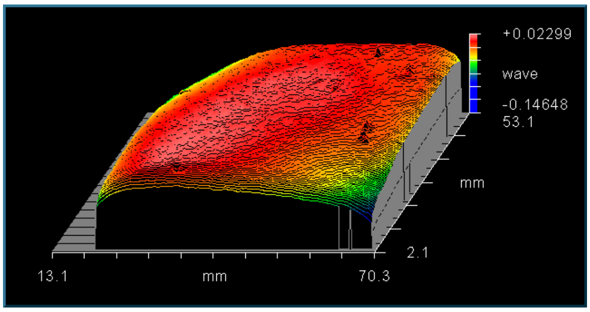

Fig. 5. Surface map of Suprasil 1 sample obtained with Zygo XP/D interferometer after irradiation. A similar overall surface shape was seen. No distinct structures corresponding to the four impact points of the proton beam were seen. The two visible spikes were attributed to an imperfect rearside coating.

1 Mrad and 10 Mrad). The 10 krad results had to be discarded due to difficulties during the irradiation run. No transmission loss due to radiation damage could be found in any of the fused silica samples with a sensitivity better than $\pm 1\%$. The super polished surfaces were studied with an interferometer and showed no changes after irradiation. All three fused silica types thus meet the requirements in terms of radiation hardness for PANDA's DIRC detectors.

The radiation hardness studies for PANDA's DIRC detectors will be complemented by an investigation of the radiation damage caused by neutrons.

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