

Influence of Quartz Glass Properties on UV-Performance of Sleeves for Systems: Working with Medium-Pressure Mercury Lamps

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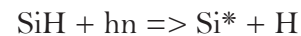
Quartz glass sleeves containing medium-pressure mercury lamps (MPLs) are subject to radiation damage due to the intense VUV- and UV-C emission of this kind of lamp. In general sleeves are made out of conventional quartz glass produced by melting pegmatite sand under reducing atmospheric conditions. The result is a “dry” quartz glass material with low OH-content and a large amount of SiH groups, which are subject to strong radiation damage reducing the UV-transmission and useful lifetime of the sleeves. Alternative materials containing SiOH in addition to SiH groups are much more resistance against radiation damage showing a self-annealing property under prolonged irradiance.

Key words: Quartz glass properties; Solarization; Radiation damage; UV-transmission;

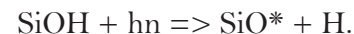
Introduction

Medium-pressure mercury lamps (MPLs) are widely used in industrial processes like drinking water disinfection, wastewater treatment and the treatment of ballast water on board ships. Photon fluxes from MPLs ranges down to wavelengths below 200 nm (Figure 1) and may cause solarization in the quartz glass sleeve material surrounding the lamp. The ageing of the lamp itself is mainly caused by the devitrification of the quartz glass envelope and sputtered tungsten from the electrodes reducing the emitted UV-C-flux by <30% during 5000-10000h of operation. Color centers formation due to the intense UV-radiation of the lamp in the quartz envelope is not an issue, because the lamp surface has a temperature well above 600°C at which all color centers are unstable. In contrast radiation with wavelengths below 230 nm are able to generate permanent defects in quartz glass near room temperature. Sleeves made out of natural fused silica are used to isolate MPLs in water applications and are especially subject to radiation damage. The useful operational time of these sleeves is limited by the generation of color centers inside the quartz bulk material affect-

ing the transmission properties in the UV-C. Depending on the production process of fused or synthetic silica a large amount of SiH and/or SiOH bonds may be present in the SiO₂-network. Related to these molecular bonds there are two typical color centers absorbing photons: the E'-center absorbing around 215 nm produced by the interaction of SiH precursors with highly energetic photons via the reaction



and the non-bridging oxygen hole centre NBOH absorbing around 265 nm due to the reaction



The transmission of conventional sleeves made out of “dry” fused silica (large SiH content) is mainly affected by formation of E'-centers.

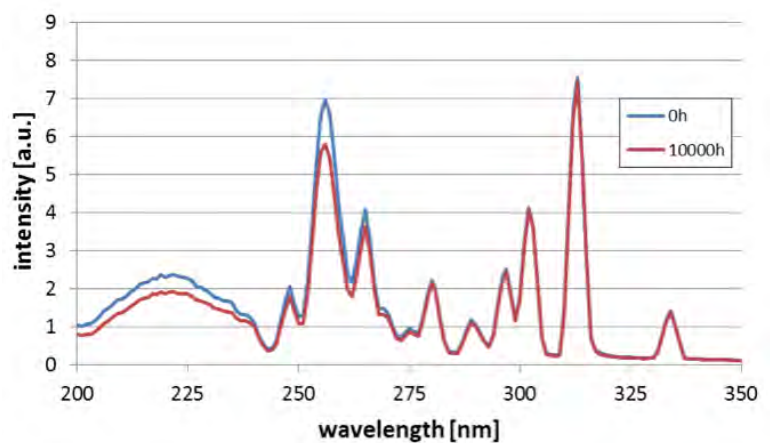


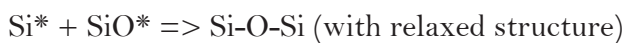
Figure 1 UV-Spectrum of a 12 kW medium-pressure mercury lamp at 0 h and after 10000 h of operation.

Experiments and Results

Ageing experiments of different quartz glass types (thickness 1mm) under VUV irradiation were performed at near room temperature. Electrically molten quartz glass samples produced from pegmatite sands with large SiH content were compared to the results obtained using SiOH containing silica. The samples were thermally annealed to relax the internal stress produced during the production process and then irradiated with VUV-photons ($\sim 30 \text{ mW/cm}^2$) in a N_2 -atmosphere. The results obtained using VUV-photons are similar to other irradiation experiments as long as the wavelength of the photons used is lower than 230nm. Sleeves returned from the field clearly show the signature of E' -formation in transmission measurements. Transmission measurements on samples were carried out off-line using a Perkin-Elmer Photometer on each sample separately after fixed irradiation times. Figure 2 shows the ageing effect of standard quartz glass typically used for sleeves with low OH-content. The transmission loss is dominated from the beginning by a monotonic increasing absorption band centred at 215 nm. This absorption band is related to the build-up of E' -defects from SiH precursors.

NBOH-defects are not produced due to the absence of SiOH groups in this conventional material with an oxygen deficient structure. The presence of oxygen deficiency manifests itself in an absorption band around 245nm related to the existence of unrelaxed O-vacancies ($\text{Si}=\text{Si}$) or divalent Si-bonds (Si-O-Si-O-Si) the so called oxygen deficient centres (ODC II). This absorption band is clearly visible in Figure 2 especially at 0h and completely absent in the case of OH-containing materials (Figure 3). Due to the monotonic increase of the E' -centers and the width of the absorption band all wavelength in the UV-C spectral range may be affected.

In the case of OH-containing silica (Figure 3) E' -centers together with NBOH-defects are formed during the first 55h of irradiation. The total loss in transmission over the complete UV-C spectral range stays well below 10%. For prolonged irradiation times the transmission loss gets smaller due to a recombination reaction between the E' - and NBOH-centers:



This effect is common to all quartz glass samples with OH-concentrations $>100 \text{ ppm}$.

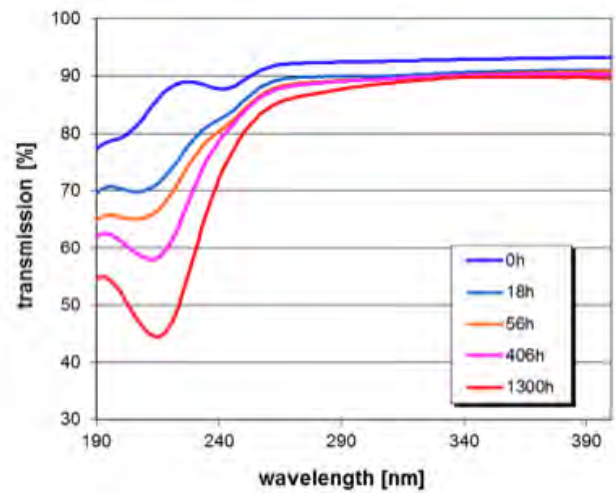


Figure 2 Transmission of standard quartz glass ($[\text{OH}] < 1 \text{ ppm}$, $d=1\text{mm}$) at different VUV-exposure times.

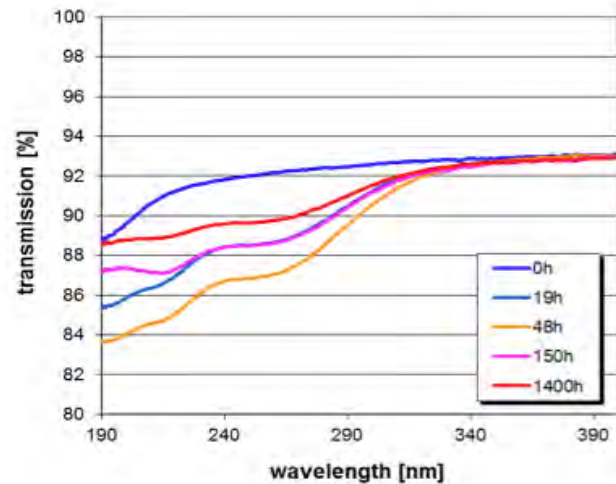


Figure 3 Transmission of SiOH containing quartz glass ($[\text{OH}] \sim 200 \text{ ppm}$, $d=1\text{mm}$) at different VUV-exposure times.

Using the known absorption cross section for E' -centers ($25 \times 10^{-18} \text{ cm}^2$) and NBOH-defects ($5.3 \times 10^{-18} \text{ cm}^2$) the average defect concentration can be calculated. The defect concentration for quartz glass with high OH-content can be calculated to be $< 2 \times 10^{16} \text{ cm}^{-3}$ for the E' -centers and $< 9 \times 10^{16} \text{ cm}^{-3}$ for the NBOH-defects respectively.

For quartz glass types with low OH-content a monotonic increase in E' -defects during irradiation is observed (Figure 4), whereas in OH-containing quartz glass the initial increase in E' - and NBOH-defects is followed by an annealing phase reducing defect concentration with irradiation (Figure 5).

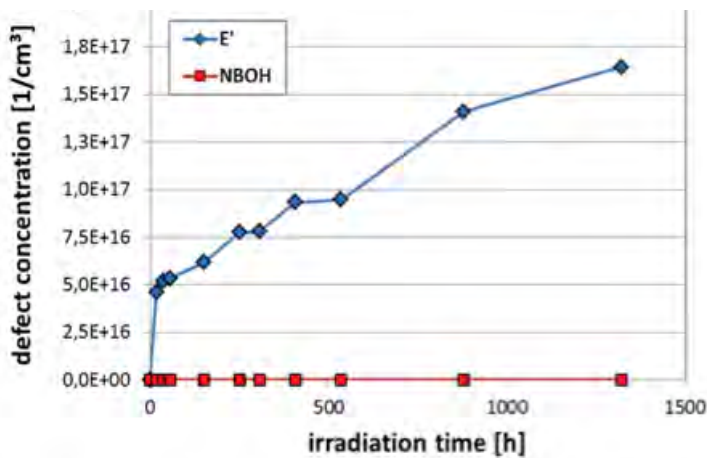


Figure 4 Defect concentrations of standard quartz glass with low OH-concentration ([OH]<1 ppm) during VUV-irradiation .

Quartz glass materials with OH-concentrations >100 ppm matches the requirements for highly UV-transmitting sleeves due to their weak radiation damage and recovery feature caused by the annealing of low NBOH and E'-defect formation.

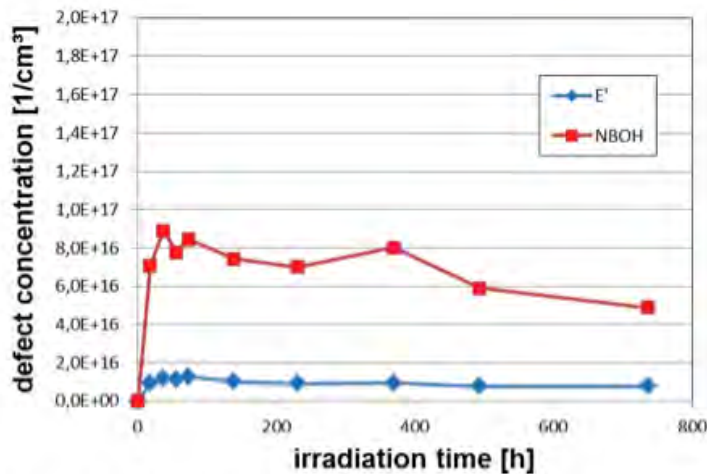


Figure 5 Defect concentrations of standard quartz glass with high OH-concentration ([OH]~200 ppm) during VUV-irradiation .

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