Degradation of opaque quartz-glass diffusers under high intensity UV irradiation

Dr. Niklas Papathanasiou*, Gabriel Hopfenmüller, Michael Matalla and Dr. Tilman Weiss, sglux GmbH, Richard-Willstätter-Str. 8, D-12489 Berlin, Germany

*corresponding author, email: papathanasiou@sglux.de

Abstract

In UV water purification applications UV sensors are monitoring the dosage of UV irradiation as according to ÖNORM and DVGW standards. sglux GmbH is manufacturing such sensors employing opaque synthetic quartz-glass diffusers as entrance windows. This paper investigates the influence of high-intensity UV irradiation on the transmission behavior of these diffusers. Quartz-glass and micro-porous quartz-glass were investigated. The sensors were continuously monitored while irradiated by a 1kW medium pressure Hg lamp with a total UV irradiance of 1000mW/cm² for 800 hours. Before and after the aging period the total transmissions of the diffusers were measured.

A 15% signal decrease of sensors employing porous quartz glass could be observed within the first 200h of irradiation. Afterwards no further degradation was detectable with the current set-up. The total transmission and reflection of the sensor windows were measured before and after the aging experiment. The total transmission between 350nm and 500nm is reduced by 7-10% due to the 800h stress while below 350nm the degradation becomes more severe. Up to 25% loss in transmission at 260nm is observed. These correlates well with the observed decrease of the sensor signal by 15%, which integrates the irradiance between 220nm and 390nm. Samples with clear quartz-glass windows show nearly no loss in transmission between 350nm and 500nm, while about 3% loss in the UVC region is detected. The origin of the reduced transmission is not clear and was not in the scope of this study. However, the results prove, that it is necessary to perform an initial UV treatment of porous quartz glass to achieve stable signal reading for UV sensor employing such diffusers.

1. Introduction

Water purification by means of high power UV irradiation generated by low pressure or medium pressure mercury lamp system is becoming frequently utilized. Therefore national health and hygiene departments stipulate technical requirements for UV water purification systems. Prominent standards are the Austrian ÖNORM 5873-1: 2001-03 and the German DVGW 294 (A): 1997-10. Both standards describe the technical and mechanical specifications for UV irradiation sensors to be used for monitoring and controlling the UV irradiation source. The UV sensor needs to fulfill among others the following parameters: Lambertian light collection by means of a field of view of 160° and a light diffusing element - in the following called diffuser; weighting of the irradiation by the micro-bicidal action spectrum in the wavelength region 240nm to 290nm. As diffuser a UV stable opaque material like PTFE has to be employed. Investigations found that PTFE show fluorescence in the UV wavelength range, when illuminate by a Deuterium lamp [1] or a 220nm laser [2]. Thus a calibration of the sensor is difficult. An alternative is micro-porous quartz-glass. sglux is manufacturing UV sensor according to ÖNORM / DVGW employing such opaque quartz-glass. In this contribution we investigate the UV stability of micro-porous quartz.

2. Experimental

Eight sensors were manufactured with quartz and opaque quartz-glass diffusers entrance windows to investigate the influence of the UV irradiance on the material. This treatment we call "UV aging". One sensor has no window as monitor sample. Additionally, the SiC chip size and hosing as well as the attenuator were varied. 4 sensors are assembled with TO5 housing and L-size chip while the other 4 employ a TO18 cap and D-size chips (s Table 1). The attenuator is a metal mesh which decreases the amount of radiation by 50%.

No.	Name	Photodiode	Attenuator	Window
1	ÖNORM-L	TO5-L-Chip	No	Without
2	ÖNORM-L-Q	TO5-L-Chip	No	Quartz
3	ÖNORM-L-D	TO5-L-Chip	No	Diffusor 2000
4	ÖNORM-L-50-D	TO5-L-Chip	50.00 %	Diffusor 2000
5	ÖNORM-DF-D	TO18-D-Chip	No	Diffusor 2000
6	ÖNORM-L-50-Q	TO18-D-Chip	50.00 %	Quartz
7	ÖNORM-DF-Q	TO18-D-Chip	No	Quartz
8	ÖNORM-DF-50-Q	TO18-D-Chip	50.00 %	Quartz

Table 1: Specification of sensors set under investigation

The synthetic micro-porous quartz-glass windows (s. Figure 1) - named Diffusor 2000 - consists of 2000 million gas bubbles per cm^3 with a diameter of about 4μm. Depending on the amount of bubbles per cm^3 the scattering profile comes close to the cosine function, thus qualifying the material as a near Lambertian diffuser. As described in Table 1 we compared sensor with just a quartz-glass window but without PTFE to avoid fluorescence artifacts. Sensor No.1 has no window and works as monitor reference to normalize signal changes due to changes in lamp intensity. It was shown in a former experiment that SiC photodiodes do not degrade under high irradiation.

Figure 1: Synthetic micro-porous quartz glass. Left side 15mm diameter and 2mm thick sensor window.

The UV irradiation load on different UV sensors was applied by 1 kW medium pressure mercury (HgMP) lamp achieving an irradiance of 1000mW/cm^2 at the point the sensor window. Up to 27 ÖNORM/DVGW style sensors can be placed around the HgMP lamp in a water-cooled aluminum housing (s. Figure 2 left). A temperature sensor verifies the operation of the cooling system. The sensors are equipped with electronic circuit providing a digital signal output employing the CAN-bus protocol. Thus an online-monitoring of the sensors is possible. In the current experiment 8 different UV sensors were measured as depicted in Figure 2 right.

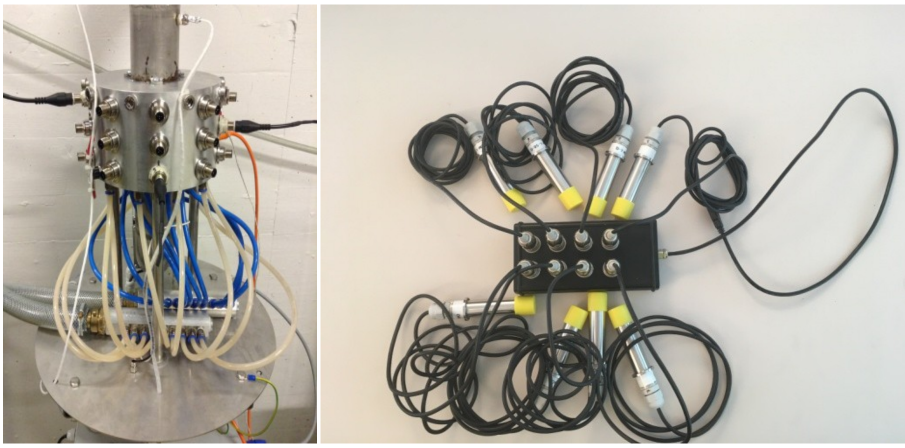

Figure 2: 1 kW medium pressure mercury lamp system with water cooled housing for 27 ÖNORM/DVGW sensors (left). 8 digital ÖNORM/DVGW equipped with CAN-bus interface box to allow online monitoring.

The output signal of the sensors was logged by a computer program with a resolution of 60 seconds. Unfortunately, the logging flailed within the first 200h twice and a medium pressure lamp broke.

Before and after the load the total transmission of a quartz window and Diffuser 2000 was measurement with a calibrated PerkinElmer Lambda9000 with integrating sphere at the Helmholtz Zentrum Berlin für Materialien und Energie (HZB).

3. Results

In the following paragraph the results of an 800h UV aging experiment are described. As the sensor have different sensitivities no direct comparison of the signal output is possible. Therefore all sensor outputs were normalized to the count rate 30min after start of the experiment. In Figure 3 the normalized signals of all 8 sensors are given. ÖNORM-L is the monitor and just normalized to the signal output after 30min. All other sensor are also normalized to their value 30min after start but in addition divided by the normalized monitor signal to remove any short term fluctuations of the HgMD lamp due to unstable power supply, arc movement and position changes of sensors.

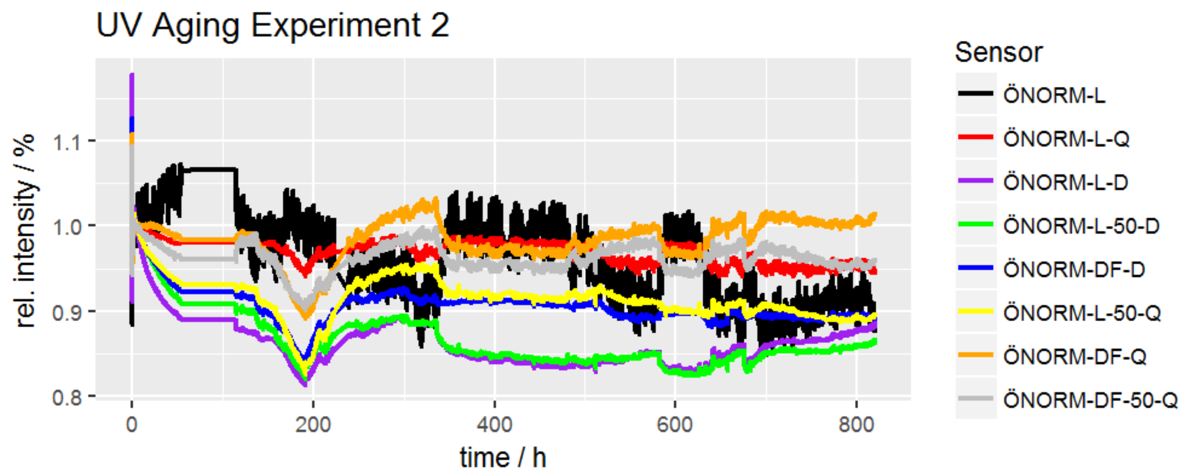

Figure 3: Normalized sensor outputs. ÖNORM-L is the monitor and used to remove short-term fluctuations in the intensity of the HgMD lamp.

Unfortunately, the data logging got an error over a weekend within the first 100h of the experiment (constant signal in the intensity vs. time plot). The drop in signal between 150h and 200h was due to the fact that the HgMD bulb was at the end of its lifetime and had to be changed. However, to major trend could be deduced from this chart. Sensors with a quartz-glass window show nearly no degradation while sensors with a synthetic micro-porous quartz window degrade by 15% to 20%.

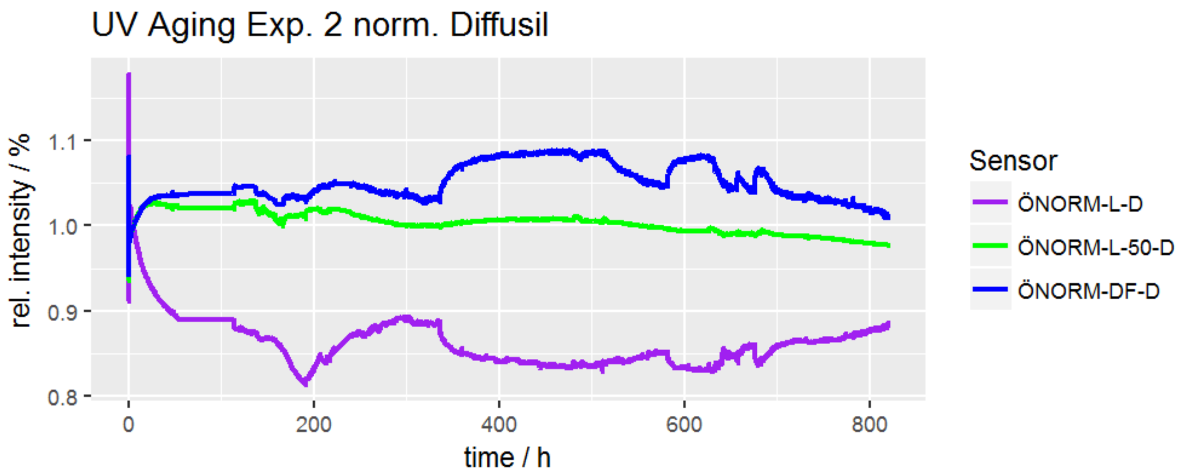

Figure 4: ÖRNOM-L-D as monitor for the two other sensors with diffuser.

In Figure 4 the degradation of the sensors with opaque quartz windows can be seen more clearly. ÖNORM-L-D is used to normalize the output of the two other sensors with opaque quartz windows. ÖNORM-L-D degrades about 15% within the first 200h. Afterwards the signal output is stable any variations are due to changes is the arc position in respect to the sensor. The normalized output of ÖNORM-L-50-D with attenuator and ÖNROM-DF-D with a smaller photodiode is stable during the whole measurement period, meaning that they degrade by the same amount. The increase in relative intensity of ÖNORM-DF-D is due to change in the arc position. The smaller diode is more sensitive as the field of view is smaller.

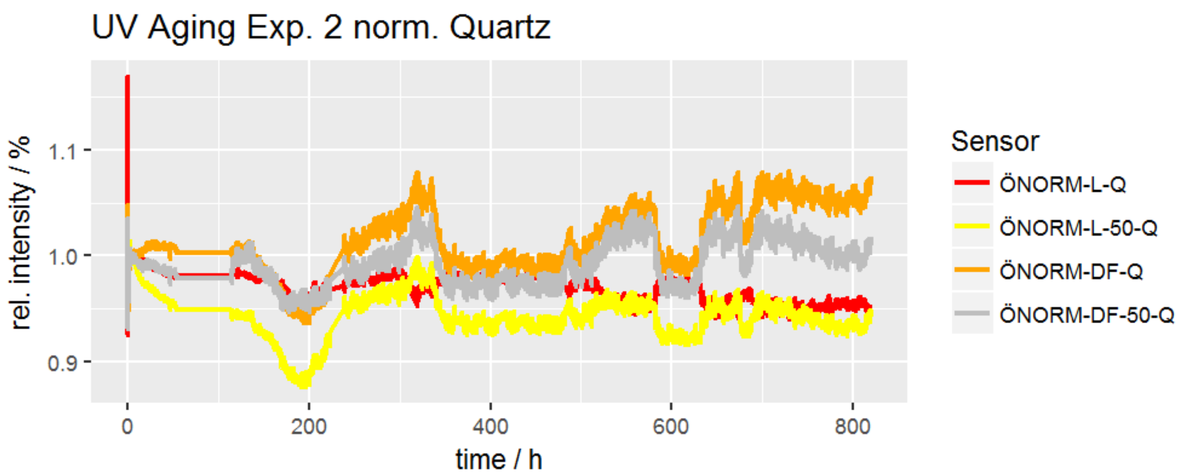

Figure 5: Normalized output of ÖRNOM-L-Q, ÖNORM-L-50-Q, ÖRNOM-DF-Q, and ÖNORM-DF-50-Q. All sensors are equipped with quartz-glass windows.

Figure 5 reveals that degradation of quartz is less than 5%. However 5% is within the uncertainty of the experiment as can be seen by the signal of both sensors with the TO18 photodiodes, which are more sensitive to variations in the UV irradiation.

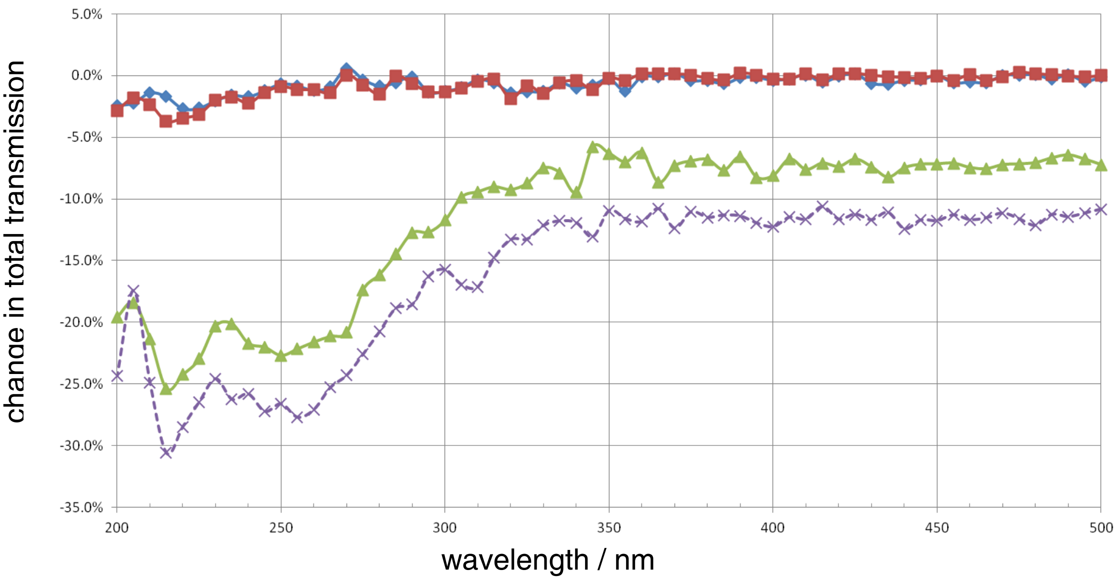

Figure 6: Change in total transmission of quartz-glass and synthetic micro-porous quartz after 800h of UV aging.

Before and after the UV aging experiment the total transmission of two quartz-glass and two opaque diffusers were measured. As can be seen in Figure 6 the quartz-glass shows no degradation due to the UV irradiation. However, the synthetic micro-porous quartz lost 10% of transmission in the wavelength range between 350 and 400nm. Below 350nm the degradation becomes more severe and a change in transmission of -25% is observed at wavelengths shorter than 260nm. The spikes below 250nm are sue to low signal and noise of the photospectrometer.

4. Summary

The experiment revealed a degradation or aging of synthetic micro-porous quartz. The ÖNORM/DVGW sensors measure at the HgMD lamp with a broad UV spectrum showed an average degradation of 15%. Total transmission measurements showed that the loss in transmission is greater in the UVC than in the UVB and UVA. However, the loss in transmission stabilizes after 200h. Thus a burn-in of sensors is necessary to avoid misguiding readings. Nevertheless, the experiment will be repeated to get better statistical evidence and to avoid experimental errors such as failing HgMD bulbs and change in sensor position.

5. Literature

[1] S. Pape, P. Sperfeld, B. Barton and K. Stock, "Analysis and reduction of fluorescence on PTFE-coated integrating spheres," in *NEWRAD 2011 - the 11th International Conference on New Developments and Applications in Optical Radiometry*, At Maui, Hawaii, USA, 2011.

[2] P.-S. Shaw, Z. Li, U. Arp and K. R. Lykke, "Ultraviolet characterization of integrating spheres," *APPLIED OPTICS,* vol. 46, no. 22, pp. 5119-5128, 01 August 2007.