TIE-42: Radiation Resistant Optical Glasses

0. Introduction

In space, nuclear power and other scientific applications optical glass may be exposed to high energy radiation like gamma-, electron, proton and neutron radiation. With the accumulation of higher doses this radiation changes the transmittance of optical glass especially near the UV-visible edge of the spectrum.

Schott offers a variety of radiation resistant glasses covering main parts of the Abbe diagram. These glasses are suitable for earth orbit based applications with lifetimes of up to 10 years. This paper gives background information on the impact of radiation on the transmittance of optical glass and how the introduction of cerium in the composition improves the radiation resistance of optical glass.

1. Origin of the effect

Ionization caused by photon and particle radiation changes the transmittance of optical glasses. An absorbed radiation dose of 10 Gy (10^3 rad) gamma radiation leads to recognizable loss in transmittance over the complete visible spectral range. The loss of transmittance is most pronounced at the UV-edge of the spectrum leading to a color change. Most glasses become unusable for optical applications if the radiation is increased to 100 Gy. The intensity of the color change does not only depend on the type of radiation dose but also on the energy of the ionizing radiation and the radiation dose rate. Other environmental conditions like temperature and illumination conditions have an impact on the extent of coloration of the glass. The coloration itself is not stable. After the end of the radiation impact the transmittance decreases slightly. This effect is called fading. The following diagram shows the effect of gamma radiation on the internal transmittance of BK7. A dose of 100 Gy reduces the transmittance over the complete visible spectral range significantly. The loss of transmittance can be further increased by increasing the dose of radiation to 10000 Gy..

SCHOTT
glass made of ideas

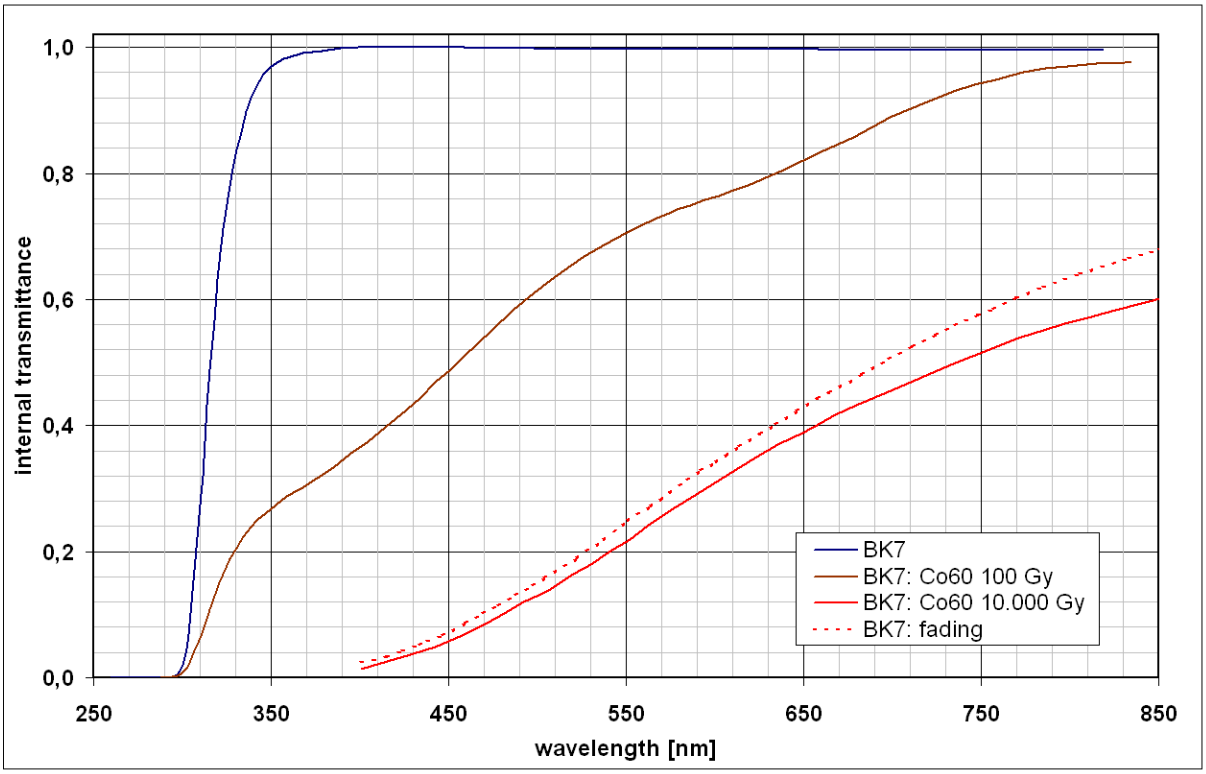

Figure 1-1: Effect of gamma radiation at different doses of absorbed radiation.

The interaction of radiation takes mainly place within the electron shell leading to electron irradiation, ionization, photo- and Compton effect.

The loss of electrons leads to defects centers of different nature: ionization, trapped electrons, trapped holes, ruptured Si-O bonds and non bridging oxygen ions. These defect centers lead to a change in the transmittance curve [1].

2. Properties of radiation resistant glasses from SCHOTT

Optical glasses can be stabilized against transmittance loss caused by ionizing radiation by adding cerium (Cer) to the composition. The added cerium (a polyvalent ion) changes the intrinsic color of the glass. The transmittance edge is shifted to longer wavelengths. In general the cerium content is kept low enough to keep this effect small.

The extent of stabilization differs from glass type to glass type. Every cerium stabilized glass type shows the letter G and a number as an additional suffix in the glass name. The number in the suffix divided by 10 relates to the additional weight percentage of CeO2 in the glass. BK7G18 for instance was stabilized against radiation by adding 1,8 w% of cerium into the BK7 glass matrix. In general the higher the cerium content the more the glass is stabilized against higher total doses but the more the intrinsic transmittance is reduced. In addition, the impact to the color change by addition of cerium depends on the glass matrix.

The modified Abbe diagram in figure 2-1 contains all currently available stabilized glass types. The diagram shows that not only the transmittance curve but also the optical position of the stabilized glass types varies slightly from the non stabilised catalog glass.

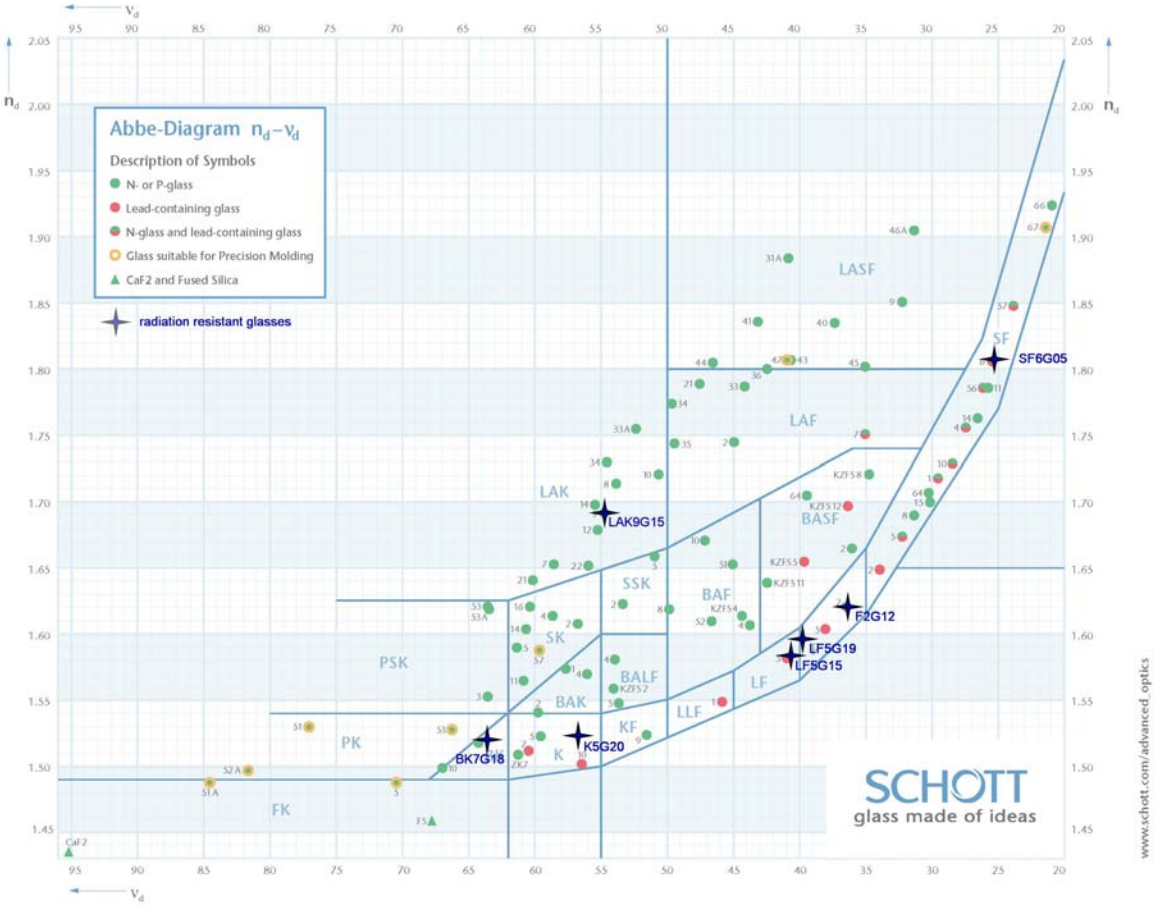

Figure 2-1: Abbe diagram showing the available radiation resistant glass types.

The following table 2-1 gives a summary of properties for the available radiation resistant glasses. Complete datasheets are available on request.

Glass Type	Glass Code	n_d	ν_d	$n_F - n_C$	n_e	ν_e	$n_{F'} - n_{C'}$	n_r	n_C	$n_{F'}$	n_g	n_h	$P_{g,F}$	$\Delta P_{g,F}$
BK7G18	520636.252	1,51975	63,58	0,008174	1,52170	63,36	0,008233	1,51579	1,51724	1,52587	1,52981	1,53345	0,5376	0,0007
LF5G19	597399.330	1,59655	39,89	0,014954	1,60010	39,60	0,015153	1,58970	1,59214	1,60799	1,61578	1,62330	0,5803	0,0036
LF5G15	584408.323	1,58397	40,83	0,014301	1,58736	40,55	0,014484	1,57739	1,57974	1,59489	1,60228		0,5759	0,0008
K5G20	523568.259	1,52344	56,76	0,009222	1,52564	56,47	0,009308	1,51906	1,52065	1,53040	1,53494	1,53919	0,5500	0,0017
LAK9G15	691548.343	1,69064	54,76	0,012612	1,69364	54,53	0,012721	1,68462	1,68680	1,70013	1,70630	1,71205	0,5462	-0,0055
F2G12	621366.360	1,62072	36,56	0,016979	1,62474	36,30	0,017212	1,61298	1,61573	1,63373	1,64261	1,65121	0,5831	0,0008
SF6G05	809253.520	1,80906	25,28	0,032015	1,81661	25,08	0,03257	1,79491	1,79988	1,83387				

Glass Type	CR	FR	SR	AR	PR	α (-30/70)	T_g	$T_{10}^{7.6}$	ρ	HK	HG	B	τ_i(10/400)	FC
BK7G18		0	1	2		7,0	585	722	2,52	580		0	0,764	41/37
LF5G19	2-3	2	3,4	2,2	3	10,7	474	606	3,30	410	2	1	0,276	45/39
LF5G15		0	1-2	2,3		9,1	415		3,23	440		1		
K5G20		0	1	1		9,0	483	679	2,59	510		1	0,821	41/37
LAK9G15	1-2	2	53,0	1,3	4,3	6,3	650		3,43	721		2	0,292	46/38
F2G12		0	1	2,2		8,1	435	605	3,60	410		1		
SF6G05	4	3	51,3	2,3	3,3	7,8	427	529	5,20	360		1		52/46*

Table 2-1: Summary of properties of the radiation resistant glasses from SCHOTT [2].

3. The effect of radiation on radiation resistant glasses from SCHOTT

The radiation resistant versions of the glasses are often slightly different in color compared to the standard glasses, as shown for one example in figure 3-2 where non stabilized N-BK7 and cerium stabilized BK7G18 are compared. BK7G18 has a yellowish color compared to N-BK7. This yellow color is shown by the shift of the UV-edge of the transmittance curve compared to N-BK7. Figure 2-3 shows a comparison of the transmittance curve of BK7G18 and BK7. Additionally the impact of 100 Gy gamma radiation (Co60) on BK7 and a much higher gamma radiation of $8*10^6$ Gy on BK7G18 can be compared. BK7 displays a strong transmittance loss over the complete spectral range whereas the reduction of transmittance of BK7G18 at a radiation amount which is 5 orders of magnitude higher is very low in comparison.

Figure 3-2: Cerium stabilized BK7G18 and non stabilized N-BK7 in direct visual comparison.

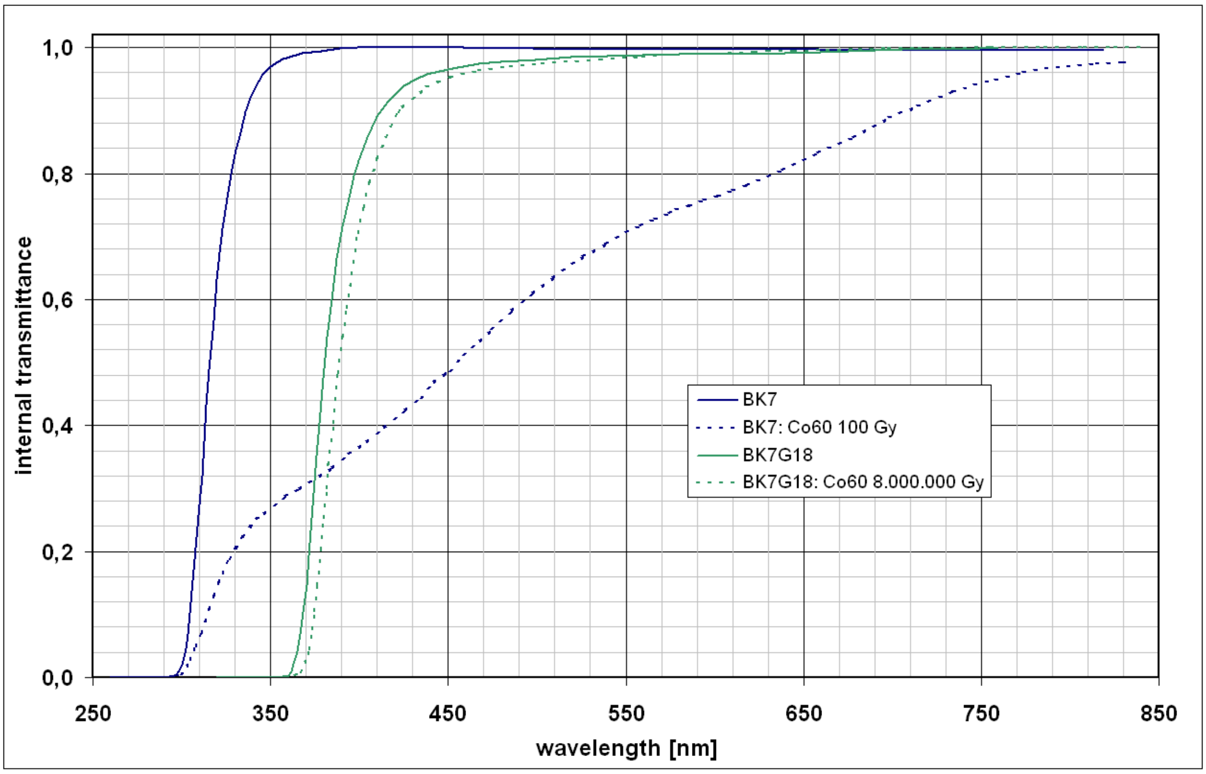

Figure 3-3: Transmittance of non stabilized BK7 and stabilized BK7G18 before and after irradiation.

As mentioned before the extent of the coloration depends on the kind of radiation and the radiation dose, which can be clearly derived from Figure 3-4 where the transmittance loss of BK7G18 for different kind of radiation: proton particle radiation, electrons, gamma and neutron radiation is shown. Neutron radiation (fluence < $0{,}15 \cdot 10^{21}$ n/m^2 in the example) has the highest impact on the transmittance of BK7G18. The effect of protons (7 to 50 MeV, dose $1{,}4 \cdot 10^{18}$ $MeV/(m^2 \cdot s)$ in the example) and electrons on the transmittance is comparable (fluence: $8{,}8 \cdot 10^{21}$ e^-/m^2, energy 0,05 MeV, radiation duration 20,6 h in the example) and in the same region as the 10^5 and 10^6 gamma radiation.

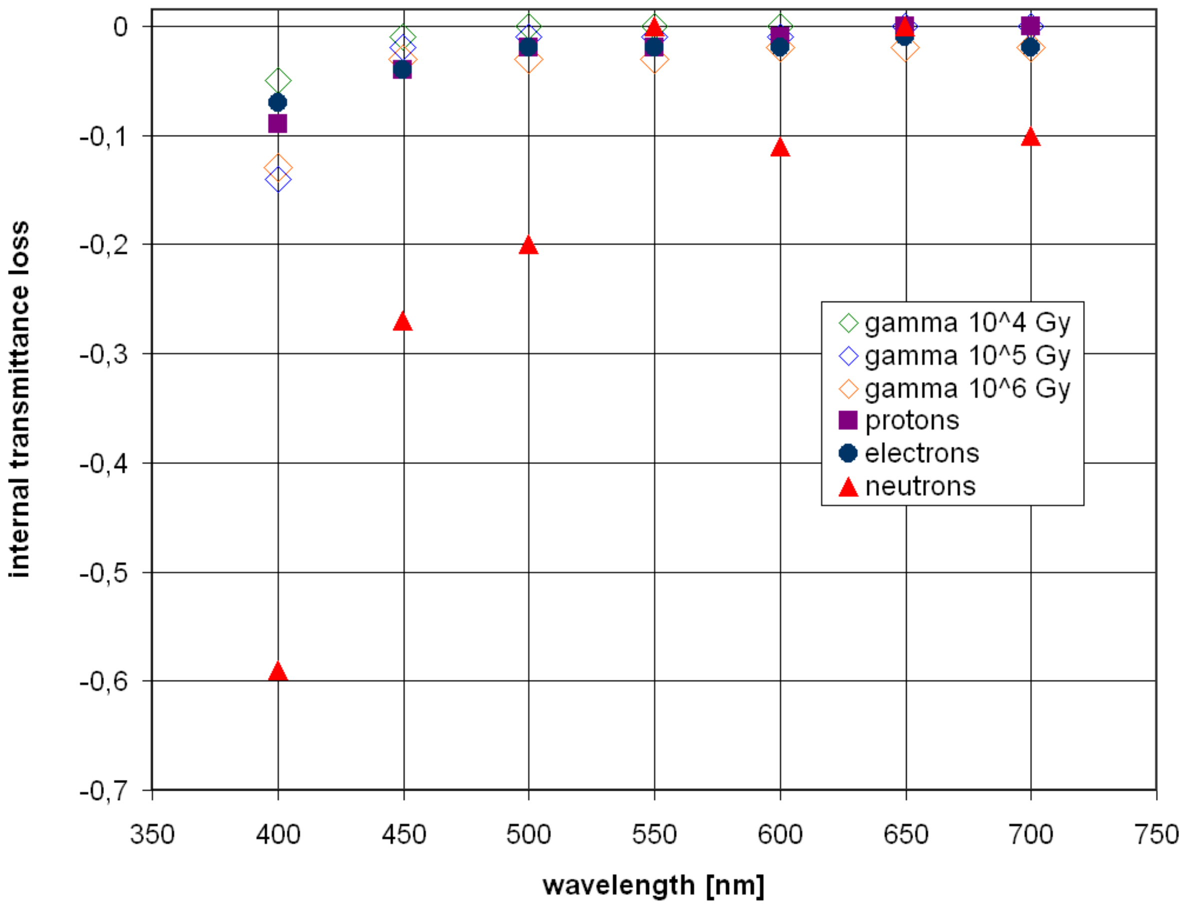

Figure 3-4: Transmittance loss of BK7G18 as a function of wavelength for different kind of radiations.

Some glasses are stabilized with a high amount of cerium and are therefore especially suitable for use in surroundings with very high radiation. Other glasses are stabilized to a lower amount. This is mostly the case if the cerium- content influences the transmittance to a higher amount. Figure 3-5 shows a comparison of the influence of gamma radiation 10^6 Gy on the internal transmittance loss over the wavelengths for different radiation resistant glasses. SF6G05 shows a significantly higher transmittance loss compared to BK7G18 or K5G20.

In general all radiation resistant glasses are suitable for earth orbit based application with lifetimes of up to 10 years.

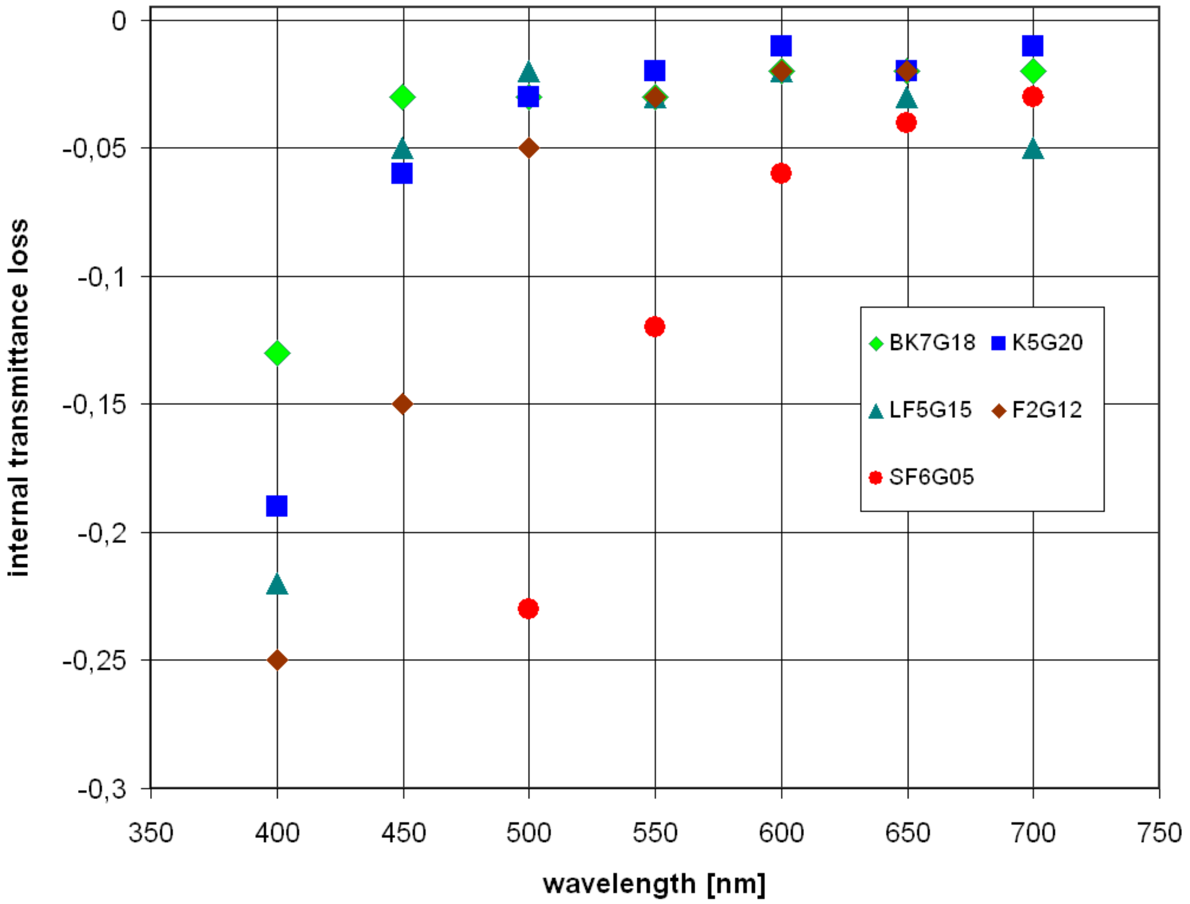

Figure 3-5: Transmittance loss of different radiation stabilized glasses as a function of wavelength for an absorption of 10^6 Gy.

4. Notes on the availability

Radiation resistant glasses are inquiry glasses which we do not purposely keep on stock. It is therefore recommended to start a request as early as possible within the project .

5. Literature

[1] The properties of optical glass; H. Bach & N. Neuroth (Editors), Springer Verlag 1998
[2] SCHOTT Optical Glass Pocket Catalogue

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