TIE-28 Bubbles and Inclusions in Optical Glass

Introduction

Optical glass in general is nearly free of bubbles and inclusions compared to other technical glasses due to sophisticated production processes, which are optimized for low bubble content. Nevertheless to specify an optical glass for a desired optical component it is helpful to know the background on the generation of bubbles and inclusions and their impact on the application. This technical information gives an overview on the topics involved in the selection of the right specification for bubbles and inclusions.

1. Generation of Bubbles in Optical Glass

The compositions of glasses are frequently given in form of oxides. In reality however raw materials used for melting may be carbonates or hydrogen-carbonates and others. Melting of such raw materials produces reaction gases forming bubbles in the melt.

These bubbles will be removed with the refining process, which is part of all glass melting. During the refining process the glass temperature is increased. The solubility of the gas components decreases. Bubbles will be formed and grow much more rapidly. The elevated temperature decreases the viscosity of the glass supporting the bubbles to move up and vanish from the melt.

Residual fine bubbles, which do not succeed to leave the melt, will be removed by chemical reactions caused by refining agents. These are elements, which change their valency during cooling down. When such an element searches for a chemical binding partner, it will take the gas of the tiny bubbles and dissolve it back into the glass. The gas atoms still will be present in the glass but not disturbing anymore.

Residual bubbles in optical glass may come from different sources. In most cases they come from non-perfect refining.

Fig. 1: Optical glass block with a small amount of bubbles.

Nevertheless a certain amount of gaseous bubbles within the glass melt during the melting process is essential to achieve a good homogenization of the melt. Ascending bubbles lead to an additional convection movement of the glass melt and therefore improve the homogenization process. Fig. 1 shows an SCHOTT N-BK7® glass sample with only a small amount of bubbles.

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The generation of bubbles by the melting and casting process is not the only possible process. Sometimes bubbles can also be generated in hot forming processes. Figure 2 shows bubble fogs generated by reheat pressing of SCHOTT N-BK7®, where the preform was damaged. Tiny bubbles were captured in a small flaw. Note: The length of the pattern in the picture is smaller than 2 mm.

Fig. 2: Bubbles generated by reheat pressing of SCHOTT N-BK7®.

2. Generation of Inclusions in Optical Glass

Inclusions (solid particles) within the glass can be generated due to:

- Remains from the batch that have not been melted completely
- Wall material with low solubility
- Particles from the outer surrounding
- Platinum particles from the tank tools
- Devitrification processes, crystallization

In general solids are gross contaminants that should be avoided if possible. Nevertheless sometimes such contaminations cannot be avoided in total due to the overall melting process. For example platinum particles can be often found in optical glasses due to the frequent use of platinum as wall material in the standard melting tank. Nevertheless such platinum particles are rather small (<0.03 mm in general) and therefore do not exhibit problems in standard applications whereas they may become important in high energy laser applications.

The prevention of devitrification processes limits some glasses to special production procedures and formats. Certain glasses show a high risk of devitrification in special temperature regions and can therefore only be produced in special sizes. Figure 3 shows crystal in N-SF6 that was generated due to devitrification.

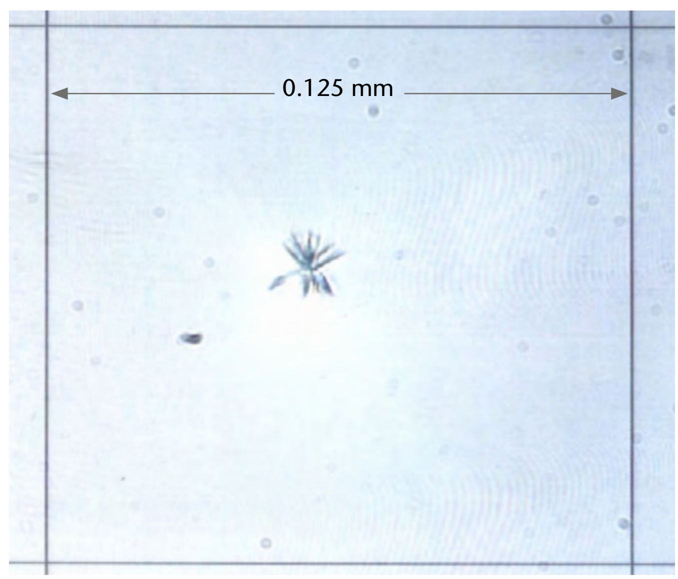

Fig. 3: N-SF6 with crystal due to devitrification.

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3. The Influence of Bubbles and Inclusions on Optical Application

In theory every part of a lens has the same imaging properties (if one may neglect image aberrations). For example covering a lens completely with only letting the light pass through a tiny spot in the upper corner one can still see the complete image but with less intensity. In figure 4 a) very simplified part of an optical system is displayed. This optical system consists of two lenses. The first lens is positioned at an intermediate image plane with the image of an arrow. The second lens images the arrow to the final image plane. Additionally four light rays are constructed. It can be seen clearly that independent from another the two upper rays and the two lower rays both image the tip of the arrow correctly. The position of the first lens in this optical system is an image plane. The position of the second lens is a pupil.

In figure 4 b) the influence of bubbles and inclusions that are located in lenses near the pupils of an optical system can be seen. They do not disturb the shape of the final image but they reduce the image contrast and intensity because part of the light is scattered. The size of this effect depends on the amount of bubbles and inclusions per area of the glass.

Bubbles and inclusions located in optical elements near the image plane can be harmful, because they might be visible in the final image (depending e.g. on inclusion size and image detector pixel size and sensitivity). This is displayed in figure 4 c). The inclusion within the first lens can be seen in the final image.

In reality lens systems consist of many different lenses and are much more complicated than the displayed example. Therefore the designer has to take into account individually the possible bubbles and inclusions in the optical system for any lens.

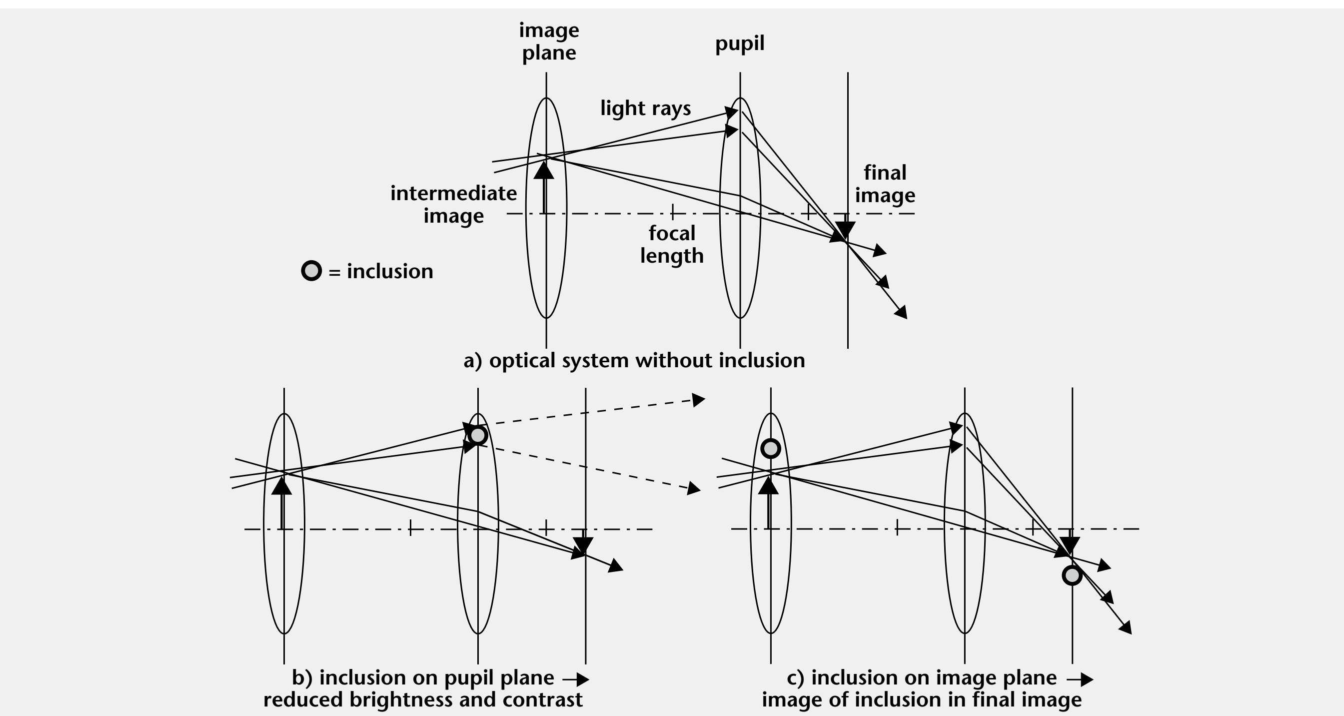

Fig. 4: The influence of bubbles and inclusions in a simplified optical system.

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4. Inspection of Bubbles and Inclusions

The inclusion quality will be assessed by visual inspection. To visualize the bubbles and inclusions the following measurement setup is used in general (figure 5). The glass is placed on a black background and illuminated from the side. The glass is viewed from above by looking through it toward the black background. The bubbles and inclusions become visible as bright spots. This arrangement is very sensitive for the quantification of bubbles and inclusions. To determine the sizes either comparison standards or microscopes are used. The evaluation includes all bubbles and inclusions with dimensions ≥ 0.03 mm. Figure 6 shows a typical view using this measurement setup.

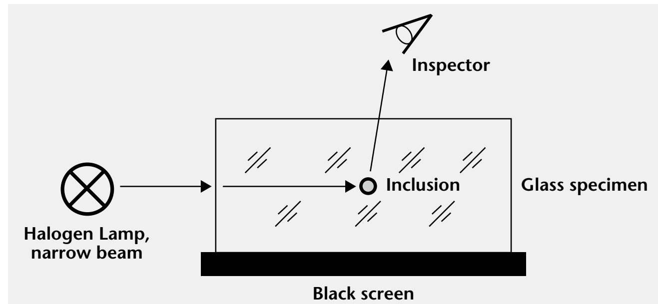

Fig. 5: Schematic measurement setup for inclusion inspection down to 0.03 mm diameter.

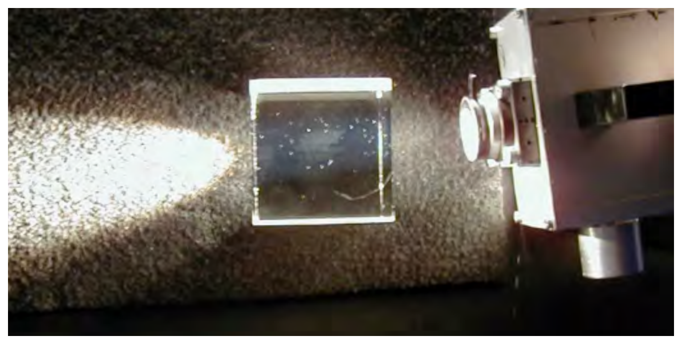

Fig. 6: View of inspected glass sample.

5. Specification

5.1 Bubbles and Inclusions

Optical glass is remarkably free of bubbles. However, due to the glass composition and the need for an economical manufacturing process, bubbles cannot be completely avoided in glass.

The bubble content is expressed by the total cross section in mm^2 in a glass volume of 100 cm^3, calculated from the sum of the detected cross sections of bubbles. Additionally the maximum allowable quantity per 100 cm^3 is defined. The evaluation considers all bubbles and inclusions ≥ 0.03 mm. Inclusions in glass, such as stones or crystals are treated as bubbles that have the same cross section.

The maximum allowable total cross sections and maximum allowable quantity of bubbles and inclusions are listed in table 1. If the inclusion cross section is not spherical, the diameter shall be the mean of the largest and the smallest distance across the field of view.

In the increased quality steps VB (increased bubble selection) and EVB (extra increased bubble selection), the glasses can only be supplied as fabricated pieces of glass.

Bubble class	Standard	VB	EVB
Maximum cross section in mm^2 per 100 cm^3 of glass volume	0.03	0.02	0.006
Maximum quantity per 100 cm^3	10	4	2

Tab. 1: Tolerances for bubbles and inclusions in optical glass.

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The largest acceptable diameter is defined by the maximum allowed cross section. Table 2 shows the maximum allowable diameter of a single bubble in different total volumes.

	Standard	VB	EVB
Max. cross section mm² per 100 cm³	0.03	0.02	0.006
Volume [cm³]	Max. allowable diameter of a single bubble [mm]		
800	0.55	0.45	0.25
500	0.44	0.36	0.20
300	0.34	0.28	0.15
200	0.28	0.23	0.12
100	0.20	0.16	0.09
50	0.14	0.11	0.06

Tab. 2: Maximum allowable cross section as a function of the volume calculated from the maximum cross section.

The customer should always indicate if the bubble and inclusion specification is only valid for the fabricated piece of glass or for the raw piece. For example if a raw glass does not fulfill the specification in total, parts of it might be within specification and can be used for the application if for example a bigger amount of only small lenses are fabricated from the raw glass.

In accordance with ISO 10110 Part 3, bubbles may be distributed. Instead of a single bubble with a given dimension, a larger quantity of bubbles of smaller dimensions is allowed (refer to [1], [2]).

5.2 Concentrations

Concentrations of bubbles and inclusions in processed parts delivered by SCHOTT (like cut blanks, pressings and others) are not allowed. A concentration occurs when there are multiple inclusions and more than 20% of the total number of inclusions occurs in any 4% of the sample. However, when the total number of inclusions found in the sample is ten or less, there must be two or more inclusions falling within a 4% area to constitute a concentration.

5.3 Laser Grade N-BK7HT

Gas bubbles and crystals are nearly irrelevant for the damage mechanism of the glass during laser irradiation. On the contrary small amounts of platinum particles with diameters <0.03 mm can lead to local damages in the glass. Therefore the bubble classes do not cover the necessary specification of platinum particles for glass with low platinum content.

N-BK7HT can be produced to a very low amount of platinum inclusions. Based on this two quality grades can be offered:

- A maximum of 10 inclusions per 100 cm³ with diameters <0.03* mm diameter in parts up to 200 mm diameter.

- A maximum of 1 inclusion per 100 cm³ with diameters <0.03* mm. The raw glass part has been completely laser damage tested using a raster scan procedure (Spectra Physics GCR 290-30: 1064 nm, 6 J/cm², 10 ns, 30 Hz, 10 shots per site continuous raster scan). The maximum possible dimensions of the parts are available on request.

Bulk Laser Damage Threshold values for SCHOTT N-BK7® at 1064 nm and 532 nm for pulsewidths of ~10 ns and 74 ps have been tested by the Laser Zentrum Hannover and published in [3].

* detection limit 0.01 mm

6. Literature

[1] ISO/DIS 10110 – part 3, "Preparation of drawings for optical elements and systems – Material Imperfections – Bubbles and Inclusions", (1996)

[2] ISO 12123, "Optics and Photonics – Specification of raw optical glass", (2010)

[3] "Recent results on bulk laser damage threshold of optical glasses", R. Jedamzik, F. Elsmann, Proc. SPIE. 8603, (2013)

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