INTERNATIONAL STANDARD

ISO 12123

Second edition
2010-04-01

Optics and photonics — Specification of raw optical glass

Optique et photonique — Spécification d'un verre d'optique brut

Reference number
ISO 12123:2010(E)

PDF disclaimer

This PDF file may contain embedded typefaces. In accordance with Adobe's licensing policy, this file may be printed or viewed but shall not be edited unless the typefaces which are embedded are licensed to and installed on the computer performing the editing. In downloading this file, parties accept therein the responsibility of not infringing Adobe's licensing policy. The ISO Central Secretariat accepts no liability in this area.

Adobe is a trademark of Adobe Systems Incorporated.

Details of the software products used to create this PDF file can be found in the General Info relative to the file; the PDF-creation parameters were optimized for printing. Every care has been taken to ensure that the file is suitable for use by ISO member bodies. In the unlikely event that a problem relating to it is found, please inform the Central Secretariat at the address given below.

COPYRIGHT PROTECTED DOCUMENT

© ISO 2010

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from either ISO at the address below or ISO's member body in the country of the requester.

ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

Published in Switzerland

Copyright International Organization for Standardization
Provided by IHS under license with ISO
No reproduction or networking permitted without license from IHS
Not for Resale

Contents

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 12123 was prepared by Technical Committee ISO/TC 172, *Optics and photonics*, Subcommittee SC 3, *Optical materials and components*.

This second edition cancels and replaces the first edition (ISO 12123:1996) and ISO 12123:1996/Amd.1:2005, which have been technically revised and substantially expanded to cover not only the specification of bubbles and inclusions, but also the specification of other important characteristics of raw optical glass.

Optics and photonics — Specification of raw optical glass

1 Scope

This International Standard gives rules for the specification of raw optical glass. It serves as a complement to ISO 10110, which provides rules specifying finished optical elements. Since raw optical glass may be quite different in shape and size from the optical elements, its specification also differs from that of optical elements.

This International Standard provides guidelines for the essential specification characteristics of raw optical glass in order to improve communication between glass suppliers and optical element manufacturers. For specific applications (e.g. lasers, the infrared spectral range), specifications based on this International Standard will have to be supplemented.

NOTE Additional information on how to translate optical element specifications into raw optical glass specifications is given in Annex A.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 7944, *Optics and optical instruments — Reference wavelengths*

ISO 9802, *Raw optical glass — Vocabulary*

ISO 10110 (all parts), *Optics and photonics — Preparation of drawings for optical elements and systems*

ISO 11455, *Raw optical glass — Determination of birefringence*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 9802 and the following apply.

3.1
refractive index

n

ratio of the velocity of the electromagnetic waves at a specific wavelength in a vacuum to the velocity of the waves in the medium

See ISO 7944.

NOTE For practical reasons, this document refers to the refractive index in air.

3.2
principal refractive index

refractive index in the middle range of the visible spectrum commonly used to characterize an optical glass

NOTE 1 This principal refractive index is usually denoted as n_d, the refractive index at the wavelength 587,56 nm, or n_e, the refractive index at the wavelength 546,07 nm.

NOTE 2 The specific values for different glass types refer to standard environmental conditions (20 °C and 1 013 hPa according to ISO 1[1]). For common daily business other reference temperatures are acceptable and will have to be quoted on demand.

3.3
refractive index variation
maximum difference of refractive index between samples of optical glasses

3.4
dispersion
measure of the change of the refractive index with wavelength

3.5
Abbe number
most common characterization of the dispersion of optical glasses

EXAMPLE 1 The Abbe number for the d-line is defined as

$$\nu_\mathrm{d} = \frac{(n_\mathrm{d} - 1)}{(n_\mathrm{F} - n_\mathrm{C})}$$

where

n_F is the refractive index at wavelength 486,13 nm;

n_C is the refractive index at wavelength 656,27 nm.

EXAMPLE 2 The Abbe number for the e-line is defined as

$$\nu_\mathrm{e} = \frac{(n_\mathrm{e} - 1)}{(n_{\mathrm{F}'} - n_{\mathrm{C}'})}$$

where

n_F is the refractive index at wavelength 479,99 nm;

n_C is the refractive index at wavelength 643,85 nm.

3.6
glass type
usually a letter/number designation used in the manufacturer's catalogue to designate or characterize the glasses offered

NOTE 1 The letter/number designation is the manufacturer's option and is usually a proprietary trade name, and therefore indeterminate. For example, borosilicate crown glass is designated N-BK by one manufacturer, but S-BSL and BSC by others.

NOTE 2 An alternative way to specify the glass type is the six-figure number called glass code, for N-BK7 e.g. 517642. It refers to the optical position of the individual glass types. The first three digits refer to the refractive index n_d, the second three digits to the Abbe number ν_d. This glass code, however, does not denominate a glass type unequivocally. The same glass code may be valid for glass types of very different chemical compositions and hence other properties may differ also very significantly.

3.7
transmittance
ratio of the transmitted luminous flux to the incident luminous flux of a collimated, monochromatic beam that passes, at normal incidence, through a plane parallel polished plate

3.8
spectral transmittance
measure of the variation of the transmittance with wavelength

3.9
spectral internal transmittance
ratio of the transmitted luminous flux to the incident luminous flux excluding reflection losses at the surfaces

3.10
UV cut-off edge
UVC 80/10
term describing the position and the slope of the transmittance cut-off edge in the short wavelength range and given by the wavelengths at 80 % and 10 % internal transmittance

3.11
colour code
CC
position and slope of the transmittance cut-off edge in the short wavelength range, given by the wavelengths at 80 % and 5 % transmittance including reflection losses

3.12
optical homogeneity
measure of the refractive index variation within a single piece of optical glass given by the difference between the maximum and minimum values of the refractive index within the optical glass

3.13
striae
short range deviations of refractive index in glass, resembling bands in which the refractive index fluctuates with a typical period of fractions of one millimetre to several millimetres

3.14
inclusion
term covering all localized bulk material imperfections including, but not limited to, bubbles, striae knots, small stones, sand and crystals

3.15
bubble
gaseous void in the bulk optical material, of generally circular cross section

NOTE Bubbles and solid inclusions are treated the same in assessing the quality of optical glass.

3.16
stress birefringence
birefringence caused by residual stresses within the glass, generally as a result of different cooling histories of different partial volumes of a given piece of glass during the forming and/or annealing process, and producing an optical path difference between the ordinary and extraordinary rays for plane polarized light passing through the glass

NOTE The optical path difference is proportional to the magnitude of mechanical stress.

4 Tolerances

4.1 Principal refractive index

The preferred tolerance ranges for the principal refractive index are given in Table 1.

Table 1 — Tolerances for principal refractive index

Principal refractive index tolerance limits
±0,002 0
±0,001 0
±0,000 5
±0,000 3
±0,000 2

4.2 Refractive index variation

Fine annealed raw glasses will be arranged in delivery lots based on the refractive index variation. Therefore, the refractive index variation shall also be specified. All parts of a delivery lot shall meet the tolerances for refractive index given in Table 2.

Table 2 — Tolerances for refractive index variation within a delivery lot

Refractive index variation tolerance limits
$\pm 30 \times 10^{-5}$
$\pm 10 \times 10^{-5}$
$\pm 5 \times 10^{-5}$
$\pm 2 \times 10^{-5}$

4.3 Abbe number

The tolerances for the Abbe number are given in Table 3.

Table 3 — Tolerances for Abbe number

Abbe number tolerance limits
±0,8 %
±0,5 %
±0,3 %
±0,2 %

4.4 Spectral internal transmittance

Spectral internal transmittance data shall be reported for thicknesses of 10 mm, and optionally 5 mm or 25 mm thicknesses. The reference thickness shall be listed in the manufacturer's catalogue or data sheet. The data shall be the typical spectral internal transmittance for a given glass type. It may be the median value of several different melts. If the buyer's requirement for melt data or minimum values for spectral internal transmittance are critical, the requirement shall be specified on the drawing or in the purchase order.

4.5 UV cut-off edge and colour code

4.5.1 General

For the description of the UV transmittance cut-off edge the so-called colour code is used. Its advantage is that it may be measured easily and cost-effectively. On the other hand, especially high index glass types hardly reach the 80 % transmittance level because of their high reflection losses. Therefore, their quality is not described very distinctly and adequately to their application as coated elements in any case. The 5 % limit may lead to ambiguous results with glass types showing fluorescence in the UV-region. Such problems may be avoided by use of the UV cut-off edge UVC 80/10.

4.5.2 UV cut-off edge

The UV cut-off edge lists the wavelengths λ_{80} and λ_{10}, in which the internal transmittance (excluding reflection losses) is 0,80 and 0,10 at 10 mm thickness. The reflection losses may be calculated using catalogue refractive index data. A UVC 80/10 measurement result, for example, may be quoted as 332/303 indicating the internal transmittances of 80 % at λ_{80} = 332 nm and of 10 % at λ_{10} = 303 nm.

4.5.3 Colour code

The colour code lists the wavelengths λ_{80} and λ_5, at which the transmittance (including reflection losses) is 0,80 and 0,05 at 10 mm thickness. The values are rounded to 10 nm and are written by eliminating the last digit. For example, colour code 33/30 indicates λ_{80} = 330 nm and λ_5 = 300 nm.

4.6 Optical homogeneity

The refractive index homogeneity that is achievable from a given glass type depends on the volume and the form of the individual glass pieces. Therefore, if it is necessary to specify the optical homogeneity of the raw glass, then this should be done with respect to the final dimensions of the optical elements to be manufactured out of the raw glass parts. In general the optical homogeneity values specified are peak-to-valley values and contain all aberrations. In many cases it is acceptable to subtract certain aberration terms that are of no importance or can easily be corrected (e.g. focal terms). This should be specified in advance.

Table 4 gives the preferred homogeneity tolerances. Lower homogeneity grades are already covered by the variation tolerances.

Table 4 — Tolerances for the homogeneity of optical raw glass

Homogeneity tolerance limits (peak-to-valley)	Generally applicable for
100×10^{-6}	common application sizes
40×10^{-6}	
10×10^{-6}	partial volumes of the raw glass
4×10^{-6}	
2×10^{-6}	partial volumes of the raw glass but not for all glass types
1×10^{-6}	

4.7 Striae

Striae tolerances of optical raw glasses are defined in terms of wavefront deviations.

Striae are generally detected by means of the shadowgraph method using comparison standards. The wavefront deviation of the comparison standard is certified in advance using an interferometer set-up. Table 5 gives the striae wavefront deviation tolerance limits.

Table 5 — Striae wavefront deviation tolerances

Striae wavefront deviation tolerance limit per 50 mm path length (nm)	**Generally applicable for**
< 60	raw glass
< 30	
< 15	partial volumes of the raw glass
< 10	

Striae are highly directionally dependent. If striae are perceived during a test, they are usually no longer detectable if inspected in a direction perpendicular to the original test direction.

Striae in optical raw glasses are in general band-like, therefore the striae wavefront deviation is dependent on the sampling thickness to a certain extent. In general the raw glass parts are inspected through the total thickness. The thickness of the finished parts is in most cases only a fraction of the initial thickness therefore the striae wavefront deviation will also be much lower. A reference thickness of 50 mm is therefore introduced to specify striae quality of general purpose raw glass.

For extremely low striae content glass pieces, it is necessary to know the optical path length and direction for the final application in order to perform adequate inspection.

In special cases the measurement can also be carried out in two directions.

4.8 Bubbles and inclusions

Inclusions in glass, such as stones or crystals are treated as bubbles of equivalent cross sectional area.

The characterization of the bubble content of a glass is performed by reporting the total cross section in mm^2 of a 100 cm^3 glass volume, calculated as the sum of the detected cross sections of bubbles. Additionally, the maximum permissible number per 100 cm^3 and the size-dependent diameter of bubbles is defined for each cross section. The evaluation includes all bubbles and inclusions with dimensions $\geqslant$ 0,03 mm equivalent diameter.

Standard permissible quantities of bubbles and inclusions in raw optical glass are given in Table 6. The rows of the table define different bubble and inclusion quality grades of optical glass combining the maximum permitted cross section and number per glass volume. It is acceptable to specify any combination of cross section and number per volume.

For strips and blocks, from which much smaller finished parts are normally produced, occasional, individual bubbles or inclusions having greater dimensions are permitted, if the limit values for the total cross section area and quantity per volume are maintained.

Bubbles and inclusions may be distributed. Instead of one bubble or inclusion with a prescribed size, a larger number of bubbles or inclusions of smaller dimensions is permissible.

The inclusion quality will be assessed by visual inspection. In critical cases measurements will be performed.

Table 6 — Permissible bubbles and inclusions within optical raw glass

Maximum permissible cross section of any bubbles and inclusions (mm^2 per 100 cm^3) **in a given glass volume**	**Maximum allowable number** (per 100 cm^3)
0,5	140
0,25	70
0,1	30
0,03	10

Concentrations of bubbles and inclusions in the final part are not allowed. A concentration occurs when there are multiple bubbles or inclusions and more than 20 % of the total number of bubbles or inclusions occurs in any 5 % of the sample area. However, when the total number of bubbles or inclusions found in the sample is ten or less, there must be two or more bubbles or inclusions falling within a 5 % area to constitute a concentration.

4.9 Stress birefringence

The size and distribution of permanent internal stresses in glasses depend on the annealing conditions (e.g. annealing rate and temperature distribution around the glass being annealed), the glass type and the dimensions. The stresses cause birefringence that is dependent on the glass type.

Stress birefringence is measured as optical path difference using the de Sénarmont and Friedel method and is stated in nanometres per centimetre based on the test thickness. A detailed description of the measurement method is given in ISO 11455.

The preferred tolerance limits are given in Table 7.

The stress birefringence in raw optical glass parts is, in most cases, larger than in the final product.

In raw glass destined to be hot processed, higher stresses are permitted, as long as they do not restrict mechanical processing.

Table 7 — Stress birefringence preferred tolerance limits for optical raw glass

Stress birefringence preferred tolerance limits (nm/cm)	**Generally applicable for**
$\geqslant 20$	raw glass
< 20	
$\leqslant 12$	
$\leqslant 6$	
$\leqslant 4$	
$\leqslant 2$	cut parts from the raw glass

5 Indications for ordering raw glass parts

The order request for raw glass parts should contain at least the following information:

a) producer of the glass and glass type;

b) refractive index and refractive index tolerance;

c) Abbe number and Abbe number tolerance.

For most applications, the refractive index homogeneity, striae, bubble and inclusion content and stress birefringence standard qualities are sufficient.

In cases where tighter refractive index variation, homogeneity, striae and bubble and inclusion tolerances are needed, the customer should indicate the tolerances necessary for the final parts together with its dimensions in the order request. The supplier will select raw glass that fulfils the desired tolerances within the necessary partial volumes.

The transmission tolerance and UV cut-off edge or colour code can optionally be specified.

EXAMPLE Schott N-BK7

n_d = 1,516 80 ± 0,001 0; lot variation: $\pm 10 \times 10^{-5}$

ν_d = 64,17 ± 0,5 %

Inclusions: 0,1 mm^2/100 cm^3, 30/100 cm^3

Partial volume size 50 mm diameter:

Optical homogeneity: 4×10^{-6} (pv)

Striae: 15 nm

Annex A
(informative)

Recommendation for the specification of raw optical glass for a given optical element specification

A.1 General

The applications of optical glass are spread over large ranges in dimensions and specifications: from small lenses of several millimetres, used in large quantities in consumer optics, up to single lenses greater than 300 mm in diameter, e.g. for use with photogrammetry and astronomical telescopes. The quality requirements span from low cost consumer optics, with only moderate requirements, to diffraction-limited objectives and high power laser optics driving the material to its very limits.

This International Standard and the optical element specification standard ISO 10110 are intended to cover a wide range of all these applications.

Part of the optical design is to specify the material quality from which the optical elements will be fabricated. This quality, however, cannot be used directly to specify the raw material from which they will be manufactured. In most cases the finished optical element comes out of only a small volume fraction of the raw glass delivery form, e.g. lenses for digital still cameras are made out of strips with volumes more than a thousand times larger than that of the lens. If one simply extends the requirements for the small optical element to those of the delivery forms, this will lead to unnecessarily high requirements, production and inspection costs. Extending the requirement of zero inclusions in a digital camera lens to the total strip glass volume, i.e. no inclusion in the total strip, would certainly make subsequent quality assurance easier, but it is not relevant to real glass production.

Additionally, due to similar economic and technical reasons the specification methods for raw glass cannot be the same for all applications. Some quality characteristics have to be treated separately for different applications or sizes or delivery forms. It makes a difference whether a lens is to be manufactured out of pressings or to be cut from a larger piece of fine annealed glass. In the first case it is a matter of the yield of the pressings. In the latter case one can optimize the lens quality by shifting the position of the lens in the gross volume. This annex gives guidance on how to proceed in some typical cases. It covers the following parameters:

- refractive index variation;
- optical homogeneity;
- striae;
- bubbles and inclusions;
- stress birefringence.

A.2 Refractive index variation

By far the most optical glass is produced in continuous melting tanks. With such production the refractive index changes with time. In order to provide material with equal properties, suppliers form delivery lots out of the continuous production with restricted variations of refractive index. Standard tolerances for these refractive index variations are given in 4.2.

The refractive index is inspected by taking samples from strips or blocks.

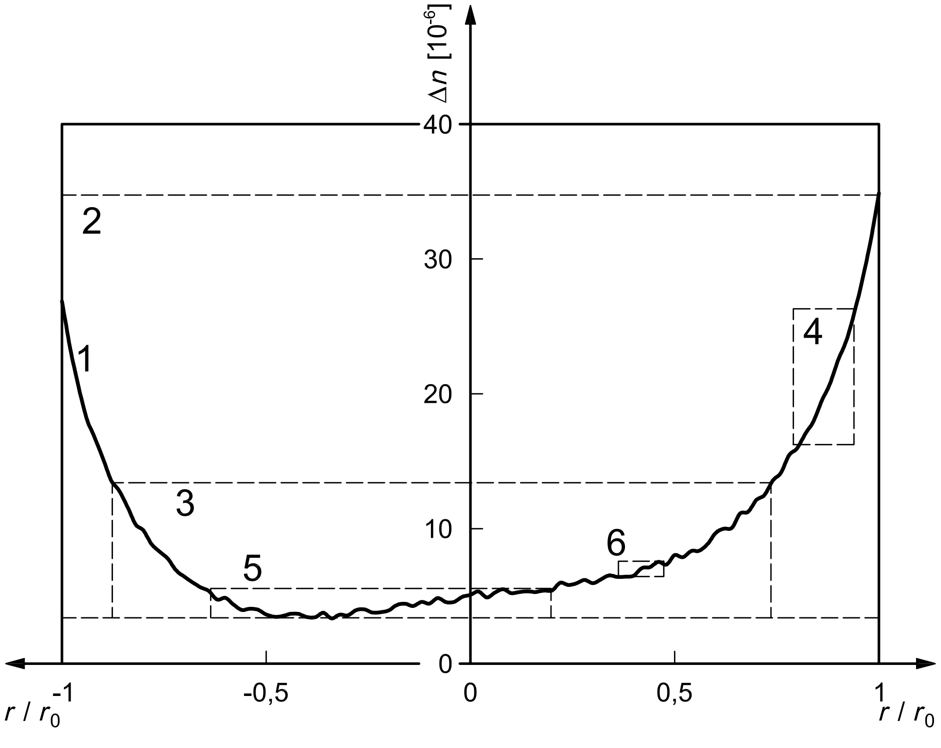
A.3 Optical homogeneity

Optical homogeneity is the variation of the refractive index within a single piece of optical glass. Usually it is measured with an interferometer.

Optical glass is specially optimized with respect to its homogeneity. For most applications it is far better than actually needed. Therefore, as a rule it is necessary to perform interferometric measurements only in cases where extreme quality has to be guaranteed.

Within cast pieces of glass, the refractive index changes smoothly in the inner part of the volume while slopes are getting steeper when one approaches the surface. Very close to the surface, in about the last millimetre, homogeneity and striae quality may degrade because of the contact with other material during production or because of some evaporation of volatile constituents of the glass. Hence, staying away from the very edge zones will improve material quality significantly.

Smaller cut pieces have much better homogeneity than the total cast piece. Within short ranges the index of refraction will change only slightly. Extending the range to the full size of the casting adds all small variations coherently. This means that a piece of glass with high homogeneity over 30 mm diameter might easily have only moderate quality over a total diameter of 180 mm. See Figure A.1.



Key

1 refractive index profile

2 homogeneity over total width, here 32 × 10^{-6}

3 maximum homogeneity range with peak-to-valley 10 × 10^{-6}

4 small partial profile with peak-to-valley 10 × 10^{-6}

5 maximum homogeneity range with peak-to-valley 2 × 10^{-6}

6 small partial profile with peak-to-valley 1 × 10^{-6}

Figure A.1 — Homogeneity of optical glass: sample refractive index profile within a glass blank demonstrating homogeneity on short ranges to be higher than that over the total width

For small lenses, for consumer optics, the homogeneity is far beyond critical application limits. Therefore, it is generally not necessary to specify it explicitly.

For larger pieces, especially for industrial optics, it may, however, become necessary to specify the optical homogeneity. In this case, it is highly recommended not to specify the homogeneity to the gross dimensions of the cut part to be delivered, but to denote the size of the finished parts. Without knowing the final element size the supplier will have to guarantee the homogeneity over the total volume of the delivery form. This may lead to high measurement effort, cost or even delivery problems, if no material fulfilling the requirement over the total volume is available.

EXAMPLE A customer orders cut glass 200 mm × 150 mm × 20 mm specifying homogeneity to be better than 2×10^{-6}. If the supplier got no additional information, he might assume that the requirement referred to the total area of 200 mm × 150 mm. As a consequence, he would inspect this area and it could happen that, as he has no part available that fulfils the requirement, he would lose money for the preparation and for making the measurement and the customer would not get any glass. But the customer meant the homogeneity specification to be for lenses of 50 mm diameter, which the glass blank might fulfil easily.

There is another aspect, which might relieve delivery problems for high-end applications. In general, the optical homogeneity values specified are peak-to-valley values and contain all aberration components. In many cases, it is acceptable to subtract certain aberration terms that are of no importance or can easily be corrected by adapting the geometry of the final part or during the adjustment of the objective (e.g. focal terms, which can amount up to one third of the total peak-to-valley value). It can be helpful to specify this in advance, such as: required residual homogeneity, 2×10^{-6} after subtraction of focal term.

For a given glass type the achievable refractive index homogeneity depends on the volume and the shape of the individual cast pieces.

In any case, the optical homogeneity within individual pieces is much better than the refractive index variation within the delivery lot i.e. from piece to piece.

A.4 Striae

The normal striae quality of general-purpose raw glass related to a reference thickness of 50 mm lies below 60 nm optical path distortion. This holds for the volume deeper than 1 mm from the surface.

Striae in optical raw glasses are in general band-like striae, extending with slowly varying intensity over partial volumes. Therefore the effective striae intensity for a given piece of glass depends on its thickness. In general, the raw glass parts are inspected through the total thickness (blocks) or a reference thickness for continuous strip glass. The thickness of the finished part is in most cases only a fraction of the initial thickness of the glass block or the reference length for strip glass. Therefore, the striae intensity in the finished part will be much lower than the inspection result for the raw glass.

Considering this intensity breakdown with the reduced effective thickness, the normal striae quality is sufficient for even most high-end applications.

If extremely low striae content is required, glass parts have to be inspected individually. Because of the directional dependence of the striae intensity, it is necessary to know the optical path length and direction for the final application. For lens applications, the thickness direction usually is sufficient, for prism applications two perpendicular directions will have to be inspected.

Usually the quality of optical glass with respect to striae and homogeneity is much better than needed for consumer applications. Glass with standard striae quality has been used successfully even for high-end applications. However, there is a risk in using glass for high-end applications which has not been specified and inspected. The failure of an optical element might be recognised at a higher value-added level and costs and time might be lost. Since the values added by polishing and coating are normally much higher than the material value, saving money by purchasing inadequate material quality might become much more expensive overall.

A.5 Bubbles and inclusions

There are significant differences in specifying the quality of the raw glass and that of the final optical elements especially with bubbles and inclusions.

The optical elements may have severe requirements on the content of bubbles and inclusions close to zero for special applications. Optical raw glass exhibits only few and small bubbles and inclusions, but cannot be produced totally free of them. Therefore, the raw glass has to be specified to allow making high quality optical elements with minimized losses. On the other hand the raw glass production must still be economical.

The way to specify the raw glass quality depends on its intended use. Will the near net shaped pressings or cut blanks be manufactured from it? Or is it intended for general purpose, not knowing specifically what will be made out of it, when it is being sold? Table A.1 gives recommendations for the specification in the different cases.

Table A.1 — Bubbles and inclusions: recommended specification of raw glass for blanks to be used for different finished optical elements

Glass blanks for optical elements	**Near net shape**			**General purpose**	
	Pressings, small diameter < 20 mm[a]	Pressings, larger diameter > 20 mm[a]	Cut blanks, any size	Small parts, diameter < 100 mm[a]	Large parts, diameter > 100 mm[a]
Typical raw glass delivery forms	Strip glass, coarse annealed	Strip glass, coarse annealed	Cut blanks	Strip or block glass, fine annealed	Strip or block glass, fine annealed
Parts per production run	> 100 000[a]	100 to 10 000[a]	100 to 1 000[a]	10 to 100[a]	< 10[a]
Optical element specification	Zero bubbles/ inclusions > 0,03 mm	N/Area Grade or size[e]	N/Area Grade or size[e]	N/Area Grade or size[e]	N/Area Grade or size[e]
Raw glass specification by	N/Vol[b]	N/Vol[b] CS/Vol[c]	N/Area[d,e] Grade or size	N/Vol[b] CS/Vol[c]	N/Vol[b] CS/Vol[c]
Quality optimization method	Press shop: preform selection	Press shop: preform selection	Glass supplier: position optimization in gross volume	Opt. polisher: position optimization in gross volume	Opt. polisher: position optimization in gross volume or parts selection

N/Vol number of bubbles and inclusions per reference volume;

N/Area number of bubbles and inclusions per area of optical element;

CS/Vol total cross section of bubbles and inclusions per reference volume;

Grade or size grades in accordance with ISO 10110-3 or individual sizes of bubbles and inclusions.

[a] The numbers given are not sharp limits. They serve for a rough orientation. Individual quality assurance measures may deviate from the values proposed here.

[b] When selecting preforms, size does not matter since cubes with bubbles and inclusion of any size will be discarded.

[c] The cross section per volume tolerance serves to reduce the probability for larger bubbles and inclusions.

[d] The same as for the finished optical element since there is no room for optimization.

[e] Subject to subdivision according to ISO 10110-3.

For small lenses for digital cameras (smaller than 20 mm to 30 mm in diameter) any bubble or inclusion might not be acceptable at all. However, this requirement must not be transferred to the raw glass specification. The yield for finished optical elements has to be optimized over the total raw glass supply chain instead.

The production of a lens is a three-step process: the raw glass production, pressing into near net shape blanks and polishing/coating. The target is to minimize the number of polished lenses exhibiting a bubble or inclusion.

There are three main influences on the average outgoing quality:

— the bubble and inclusion content of the raw glass;

— inspection of the strip glass and selection of the preforms at the press shop;

— inspection during finishing of the lens.

Improving glass quality at the first stage increases glass costs sharply by high percentages or even factors. At the second stage, costs increase due to reduced glass yield, but only at an acceptable low level. See Figure A.2. At the last stage, additional losses due to the already added value appear. Experience shows that the most economic compromise for lenses produced via reheat pressing is to specify raw glass quality to achieve losses below about 2 % during production and inspection of pressings. The inspection during pressing production should reduce the average outgoing quality by more than a factor of twenty. Thus, a final level of non-usable polished lenses may be kept well below 0,1 %.

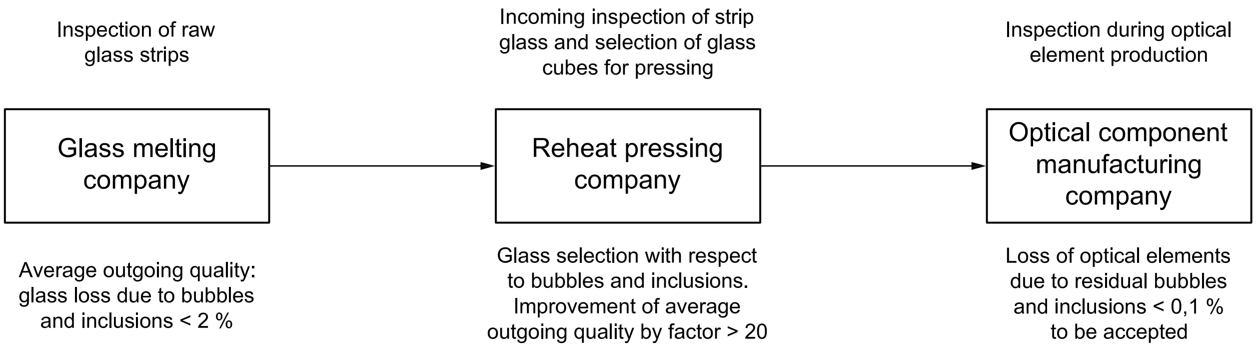


Figure A.2 — Supply and Q.A. chain for raw glass for reheat pressings with requirement for zero bubbles and inclusions (B/I) in finished lens (lenses for digital still cameras)

For larger lenses the requirement for zero bubble and inclusion content of pressings or cut discs is no longer economical. Even though there is still a high amount of pieces free from bubbles and inclusions, certain maximum bubble sizes and numbers per element will have to be accepted. Optical glass in general purpose delivery forms, like fine annealed block or strip glass, will be specified limiting the total cross section and the number of the bubbles and inclusions per reference volume. Bubble and inclusion size limits hold only for near net shape cut blanks.

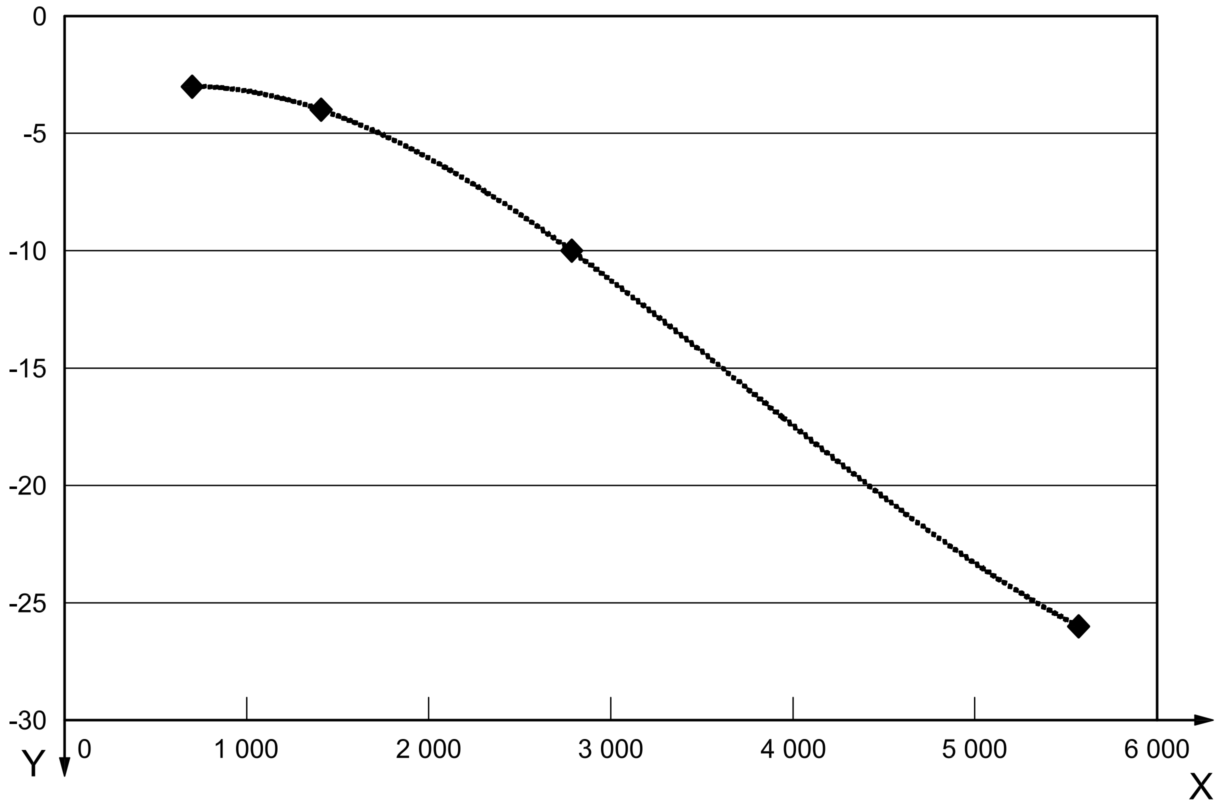
A.6 Stress birefringence

The size and distribution of permanent internal stress in glasses depends on the annealing conditions. The temperature differences within the glass part, which arise during cooling down, influence the resulting stress decisively. Being a low thermal conductor, glass reacts with high temperature differences throughout its volume when it is cooled down rapidly. In order to obtain low stress, cooling down has to be done slowly to keep such temperature differences small, particularly in the range down to about 150 °C below the transformation temperature (see Reference [2]). The transformation temperature is a material constant for a specific glass type. With increasing thickness, glass pieces show much higher temperature differences in their volumes for the same cooling rate. Therefore, larger pieces of optical glass have to be cooled down much slower. The mechanical stress causes optical birefringence within the glass. For a given stress level, the resulting birefringence depends on the glass type. The proportionality coefficient is called the stress optical coefficient.

The cooling rate also influences the refractive index and, somewhat less, the dispersion; the slower the rate, the higher the refractive index. For given melts it may happen that narrow tolerances of the refractive index and the requirement on specially low stress birefringence cannot be fulfilled simultaneously.

Stress birefringence is measured as optical path difference between light rays with perpendicular polarization directions and is stated in nanometres per centimetre based on the test thickness. For inspection, the de Sénarmont and Friedel method is widely used. A detailed description of the method is given in ISO 11455.

The stress birefringence values of a fine annealed block or strip glass will result in significantly lower values, when smaller parts are being cut out of them. Figure A.3 shows the reduction of the stress birefringence for parts cut from an original glass block with 26 nm/cm.



Key

X volume, in cubic centimetres

Y stress birefringence, in nanometres per centimetre

Figure A.3 — Example for breakdown of stress birefringence with cutting a glass block to smaller pieces (negative values mean compressive stress)

For small pressings, the fine annealing process always reduces stress birefringence down to a level far below 5 nm/cm.

For large blanks, much longer annealing times become necessary. This is because the temperature differences developing in glass during cooling down increase with the square of the thickness. The time needed, spans from days for pressings up to months for large blanks with thickness higher than 200 mm.

Bibliography

[1] ISO 1, *Geometrical Product Specifications (GPS) — Standard reference temperature for geometrical product specification and verification*

[2] ISO 7884-8, *Glass — Viscosity and viscosmetric fixed points — Part 8: Determination of (dilatometric) transformation temperature*

ICS 81.040.10

Price based on 15 pages