US 20230192528A1

(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2023/0192528 A1**

Ritter et al. (43) **Pub. Date: Jun. 22, 2023**

(54) **OPTICAL GLASS WITH HIGH REFRACTIVE INDEX**

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(21) Appl. No.: **18/086,157**

(22) Filed: **Dec. 21, 2022**

(30) **Foreign Application Priority Data**

Dec. 21, 2021 (DE) 10 2021 134 139.6
Jan. 26, 2022 (DE) 10 2022 101 785.0
Jun. 1, 2022 (DE) 10 2022 113 837.2

Publication Classification

(51) **Int. Cl.**
C03C 3/068 (2006.01)
C03C 13/04 (2006.01)
G02B 1/02 (2006.01)

(52) **U.S. Cl.**
CPC ***C03C 3/068*** (2013.01); ***C03C 13/045*** (2013.01); ***G02B 1/02*** (2013.01)

(57) **ABSTRACT**

An optical glass has a refractive index n_d of more than 2.10 and includes at least TiO_2, $NbO_{2.5}$, $LaO_{1.5}$, SiO_2, and B_2O_3. The glass has the following features: a cation parameter K of $1.8<K\leq 2.8$, wherein $K=(Ti\text{-eq.}+SiO_2+(BO_{1.5})/2)/(La\text{-eq.})$, the molar fractions of Ti-eq., SiO_2, $BO_{1.5}$ and La-eq. in the cation parameter K being in cat %; a sum total of glass components SiO_2 and B_2O_3 of 8.0 mol $\%\leq(SiO_2+B_2O_3)\leq 20.0$ mol %, the proportion of B_2O_3 being >0 mol % and the proportion of $SiO_2>0$ mol %; and a temperature $T_{max}\leq 1330°$ C.

FIG. 1

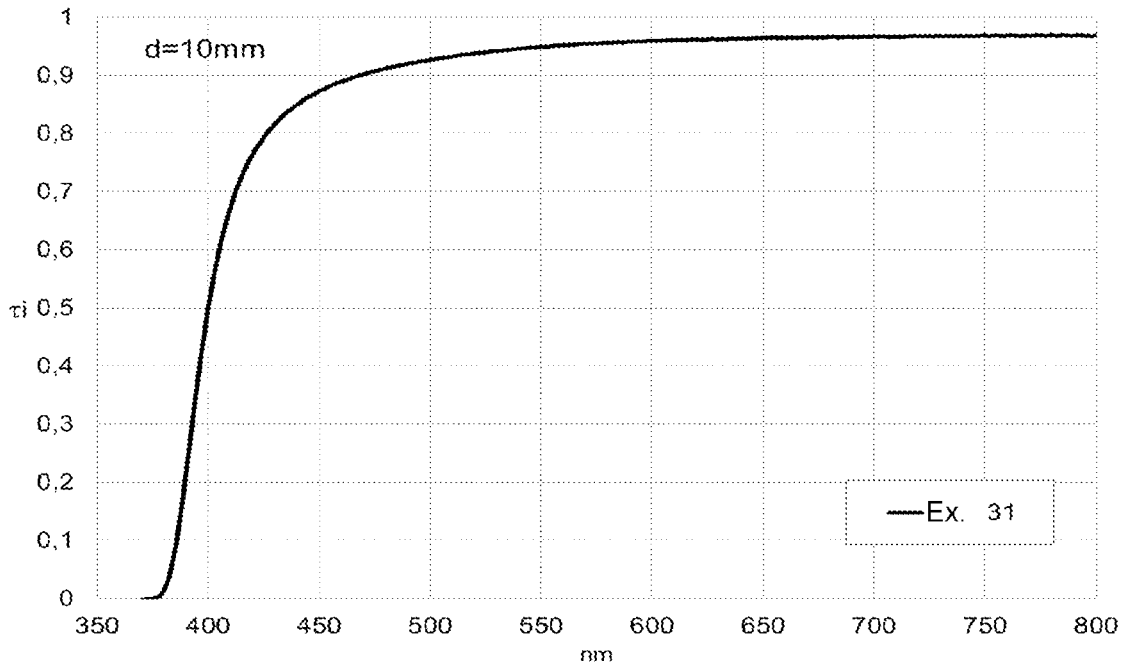

d=10mm
τi
nm
Ex. 31
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
350
400
450
500
550
600
650
700
750
800

FIG. 2

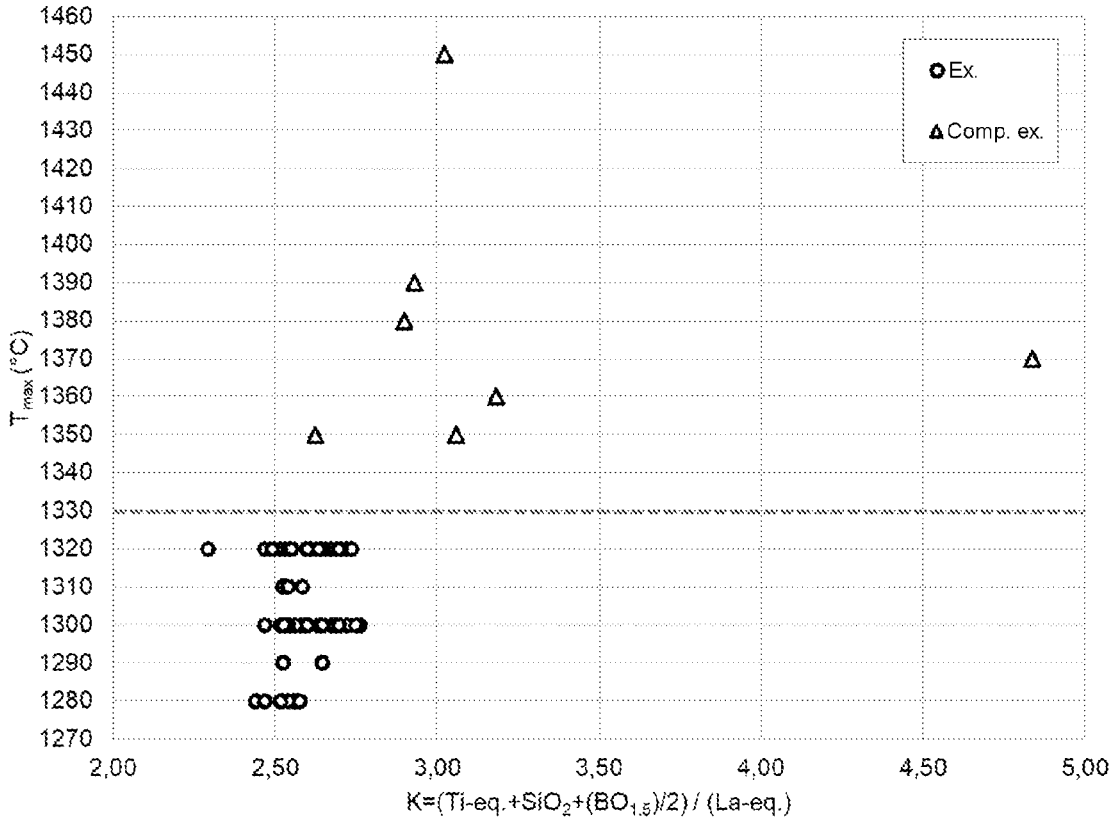
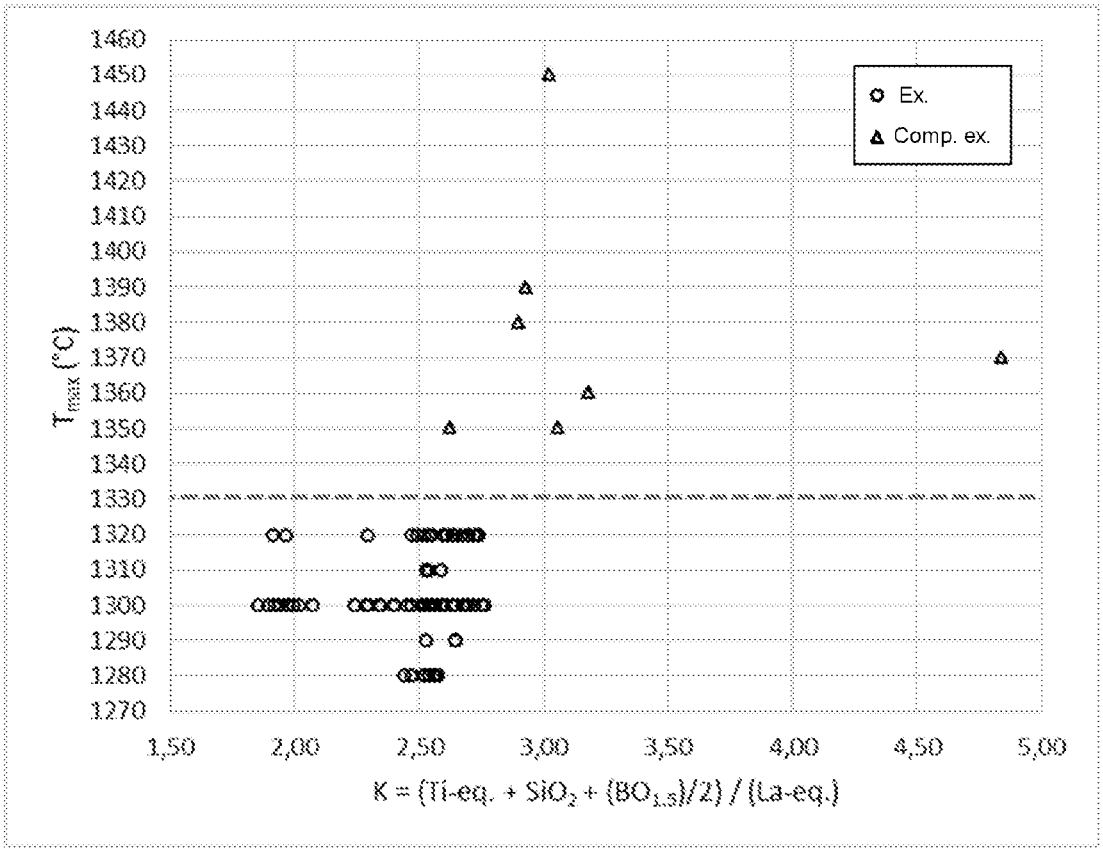

Ex.
Comp. ex.
T_{max} (°C)
K=(Ti-eq.+SiO_2+($BO_{1.5}$)/2) / (La-eq.)
1460
1450
1440
1430
1420
1410
1400
1390
1380
1370
1360
1350
1340
1330
1320
1310
1300
1290
1280
1270
2,00
2,50
3,00
3,50
4,00
4,50
5,00

FIG 3.


1460
1450
1440
1430
1420
1410
1400
1390
1380
1370
1360
1350
1340
1330
1320
1310
1300
1290
1280
1270
T_{max} (°C)
1,50
2,00
2,50
3,00
3,50
4,00
4,50
5,00
K = (Ti-eq. + SiO_2 + ($BO_{1.5}$)/2) / (La-eq.)
Ex.
Comp. ex.

OPTICAL GLASS WITH HIGH REFRACTIVE INDEX

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to German Patent Application No. DE 10 2022 113 837.2 filed on Jun. 1, 2022, which is incorporated in its entirety herein by reference. This application also claims priority to German Patent Application No. DE 10 2022 101 785.0 filed on Jan. 26, 2022, which is incorporated in its entirety herein by reference. This application also claims priority to German Patent Application No. DE 10 2021 134 139.6 filed on Dec. 21, 2021, which is incorporated in its entirety herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0002] The invention relates to an optical glass, to a glass article and to the use thereof.

2. Description of the Related Art

[0003] The invention concerns glasses that can be used in the optics and lenses sectors and also in metaoptics and in "augmented reality" (AR). The latter is understood as meaning the augmentation of reality, especially with visually presented, computer-generated information. Augmented reality is realized with the aid of special AR eyeglasses. Inside these is in each case an optical component comprising one to three planar waveguides made of glass. The waveguides in turn have integrated gratings, in each case for a wavelength in the red, green or optionally blue region of the visible spectrum. Via these gratings, the imaginary image or information is incoupled/outcoupled in the waveguide to make it visible to the eye. A high refractive index in the glass substrates serving as waveguides has the advantage that it is possible to achieve a wide field of view (FoV). The FoV is here determined by the lowest refractive index in the system, i.e. by the refractive index of the glass in the red region of the spectrum. Preference is therefore given to glasses that in addition to a high refractive index n_d at 587.6 nm also have a relatively high Abbe number and accordingly low dispersion. Metaoptics are understood as meaning nanooptics on a structural scale considerably smaller—for example by a factor of 5 or a factor of 10—than the wavelength of light.

[0004] Heavy glass components, i.e. components having a high molar mass, help increase the refractive index, also referred to as the refractive power, but at the same time increase the density of glasses, which is disadvantageous. The density of such glasses here often increases disproportionately with increasing refractive index. This means that, even with a possibility of making glass substrates thinner for use in AR, the glass substrate would become heavier, making AR eyeglasses uncomfortable to wear for long periods. Given the trend for headsets to become more like standard spectacles in shape, which are then to be worn for longer or—like normal spectacles—at all times, there is a need for the eyeglasses to become lighter. Such a reduction on weight is an advantage for other fields of use too, since camera optics in the DSLR sector are also very often either very bulky or very heavy, which also significantly increases the battery power requirement of the autofocus.

[0005] In addition, high-refractive-index glasses optionally have particularly good internal transmission τ_i in the visible wavelength range. In the case of particularly high-refractive-index glasses, a particular problem in this context has proved to be the internal transmission in the lower visible wavelength range, for example in the blue region from 420 nm to 490 nm, inter alia at 420 nm, 450 nm or 460 nm. Reference is in this context often made to what is known as the "UV edge" of the glass, i.e. the fall in the transmission curve from the visible region of the spectrum to the adjoining UV region. When the UV edge is shifted too far into the visible region or does not rise steeply enough, the transmission characteristics in the lower visible wavelength range are not sufficiently satisfactory for some uses and glasses often have a yellow tinge. Moreover, it has proven difficult to provide glasses having a particularly high refractive index across the entire visible range (in particular from 380 nm to 800 nm).

[0006] A further problem with high-refractive-index glasses is that such glasses have a high liquidus temperature, i.e. the temperature at which melt and solid/crystal are in equilibrium. Below the liquidus temperature, crystals separate out from the melt. Since high-refractive-index glasses have a reduced content of glass formers and very low viscosity, going below the liquidus temperature of such glasses leads very quickly to the formation of crystals, since crystallization is subject to very little kinetic inhibition due to the "thickness" of the melt, or none at all. A high liquidus temperature is accordingly accompanied by high melting temperatures. A high liquidus temperature is moreover disadvantageous, since at high temperatures an interfering ingress of refractory material (particularly platinum in dissolved and particulate form) can occur. In addition, higher temperatures can result in polyvalent glass components (especially niobium and tantalum) undergoing partial reduction and being present in each case in lower oxidation states, which can lead to the glass acquiring an interfering coloration and to decreased internal transmission. Low internal transmission distorts the color impression of a projected image in AR eyeglasses and in other optical components too. A high liquidus temperature also increases the manufacturing costs of high-refractive-index glasses.

[0007] Some of the glasses in the prior art derive from the niobium phosphate system or titanium phosphate system; they therefore comprise considerable proportions of P_2O_5 and niobium and/or titanium. These glasses, especially the niobium phosphate glasses, have a refractive index of less than 2.1 and are in some cases very problematic in production, since loss of oxygen, for example due to excessively high melting and refining temperatures in a phosphate system that is in any case already reducing, can result in lower oxidation states. In the case of niobium, this is for example an oxidation state of less than V and, in the case of titanium, of less than IV. This can result in an intense brown or even black coloration in the niobium system or in a yellow-green-blue to brown coloration in the titanium system. In addition, the titanium in the titanium phosphate system increases the tendency to crystallization significantly, which in the heavy flint sector is a known problem of the existing high-refractive-index glasses, which are then for example no longer re-pressible. Unlike niobium, even the highest oxidation state of titanium absorbs at the edge of the

visible range (towards the UV range), which at higher contents gives rise to the known yellow tinge of barium-titanium silicates.

[0008] Furthermore, the niobium phosphate family of glasses—like the high-refractive-index heavy flint or lanthanum heavy flint family—has a tendency not just to interfacial crystallization, but also shows very rapid crystal growth, which makes post-cooling (tension cooling or setting the refractive index) critical for optionally preseeded glasses. The glass is moreover known to be relatively brittle and therefore difficult to polish into very thin wafers.

[0009] DE 102006030867 A1 describes optical glasses having a refractive index n_d of 2.000 and higher. The glasses disclosed therein have high contents of barium oxide, which has an adverse effect on glass formation and on the refractive index.

[0010] US 20160194237 A1 describes optical glasses that comprise silicon, boron, lanthanum, titanium, niobium, and zirconium but which generally have a refractive index of less than 2.10. EP 3845503A1, JP 2020 59629 A1 and WO 2021085271 A1 disclose only glasses having a refractive index of less than 2.10, in most cases lower even than 2.05.

[0011] What is needed in the art is a way to provide optical glasses that overcome the disadvantages of the prior art. What is also needed in the art is a way to provide glasses that have a high refractive index n_d alongside a liquidus temperature that is as low as possible and advantageously an internal transmission that is as high as possible and a relatively high Abbe number. The glass would advantageously have a density that is as low as possible, readily undergo heat-forming, and be easy to work with.

SUMMARY OF THE INVENTION

[0012] In some exemplary embodiments provided according to the invention, an optical glass has a refractive index n_d of more than 2.10 and includes at least TiO_2, $NbO_{2.5}$, $LaO_{1.5}$, SiO_2, and B_2O_3. The glass has the following features: a cation parameter K of $1.8<K\leq 2.8$, wherein $K=(Ti\text{-eq.}+SiO_2+(BO_{1.5})/2)/(La\text{-eq.})$, the molar fractions of Ti-eq., SiO_2, $BO_{1.5}$ and La-eq. in the cation parameter K being in cat %; a sum total of glass components SiO_2 and B_2O_3 of 8.0 mol $\%\leq(SiO_2+B_2O_3)\leq$20.0 mol %, the proportion of B_2O_3 being >0 mol % and the proportion of SiO_2>0 mol %; and a temperature $T_{max}\leq$1330° C.

[0013] In some exemplary embodiments provided according to the invention, a glass article includes an optical glass. The optical glass has a refractive index n_d of more than 2.10 and includes at least TiO_2, $NbO_{2.5}$, $LaO_{1.5}$, SiO_2, and B_2O_3. The glass has the following features: a cation parameter K of $1.8<K\leq 2.8$, wherein $K=(Ti\text{-eq.}+SiO_2+(BO_{1.5})/2)/(La\text{-eq.})$, the molar fractions of Ti-eq., SiO_2, $BO_{1.5}$ and La-eq. in the cation parameter K being in cat %; a sum total of glass components SiO_2 and B_2O_3 of 8.0 mol $\%\leq(SiO_2+B_2O_3)\leq$20.0 mol %, the proportion of B_2O_3 being >0 mol % and the proportion of SiO_2>0 mol %; and a temperature $T_{max}\leq$1330° C. The glass article is in the form of a glass substrate, a wafer, a lens, a spherical lens, a prism, an asphere, an optical waveguide, a fibre, and/or a plate

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] The above-mentioned and other features and advantages of this invention, and the manner of attaining them, will become more apparent and the invention will be better understood by reference to the following description of embodiments of the invention taken in conjunction with the accompanying drawings, wherein:

[0015] FIG. **1** illustrates an internal transmission spectrum of exemplary glass **31** from Table 1;

[0016] FIG. **2** illustrates the relationship of the cation parameter K and Tmax for exemplary embodiments and comparative examples from Tables 1 to 9 and 14; and

[0017] FIG. **3** shows the relationship of the cation parameter K and Tmax for exemplary embodiments and comparative examples from the tables.

[0018] Corresponding reference characters indicate corresponding parts throughout the several views. The exemplifications set out herein illustrate embodiments of the invention and such exemplifications are not to be construed as limiting the scope of the invention in any manner.

DETAILED DESCRIPTION OF THE INVENTION

[0019] In some embodiments, the invention relates to an optical glass having a refractive index n_d of more than 2.10 that comprises at least TiO_2, $NbO_{2.5}$ and $LaO_{1.5}$, the glass having the following features:

[0020] a cation parameter K of $1.8<K\leq 2.8$, where $K=(Ti\text{-eq.}+SiO_2+(BO_{1.5})/2)/(La\text{-eq.})$, the molar fractions of Ti-eq., SiO_2, $BO_{1.5}$ and La-eq. in the cation parameter K being in cat %,

[0021] a sum total of glass components SiO_2 and B_2O_3 of 8.0 mol $\%\leq(SiO_2+B_2O_3)\leq$20.0 mol %, the proportion of B_2O_3 being >0 mol % and the proportion of SiO_2>0 mol %.

[0022] a temperature $T_{max}\leq$1330° C.

[0023] Exemplary embodiments provided according to the invention are based to a large extent on the correct setting of the molar fractions of cations of the glass components with respect to one another. It is therefore convenient to characterize the composition of the glass by specifying it in cat %. The glass does also contain anions, in particular oxygen. However, the properties of the glass provided according to the invention are determined less by the anions, consequently the core of the embodiments provided according to the invention lies more in the composition of the cations.

[0024] The term "cation-percent" (cat % for short) relates here to the relative molar fractions of the cations based on the total cation content of the glass. The glass does also contain anions, the relative molar fractions of which are described in anion-percent (an %) based on the total anion content of the glass. In the context of the invention, the cations are in each case specified in the highest oxidation state and shown charge-compensated with oxygen as anion. This does not mean that the cations are necessarily present in glass exclusively in the highest oxidation state. For example, in the case of arsenic and antimony, there may be cations in the trivalent oxidation state and in the pentavalent oxidation state present side-by-side in the glass. For better clarity, the element name of a composition, for example "niobium", is also used in the description of the composition of the glass. This stands in this instance for "cations of niobium" and thus does not imply that niobium is present in elemental form in the glass.

[0025] In addition to the cations, the glass provided according to the invention also includes anions, which are optionally selected from the group consisting of O^{2-}, F^-, Br^- and Cl^-. The molar fraction of O^{2-} can optionally be at least

50% (an %), at least 70%, at least 90%, or at last 99%, based on the anion content. In some embodiments, the glass contains only O^{2-} as anion and is free of other anions.

[0026] Some compositional features are better described in terms of the molar fraction of the oxidic glass component. In such cases, the individual glass component or the sum total of the glass components is given in mol %. Values in mol % can be calculated from the glass composition specified in cat %.

[0027] In the context of the invention, a glass system comprising SiO_2 that has a high TiO_2 content has been found that—unlike the glasses produced from the niobium phosphate system or titanium phosphate system that are described in the background—are more stable in respect of the internal transmission that can be achieved and have a higher refractive index but yet a relatively low density. As the refractive index increases, so does the tendency to devitrification. An inventive glass has nevertheless been found that has n_d>2.10 and is similarly stable in respect of devitrification to the known titanium-, niobium- and lanthanum-containing glasses.

[0028] An optical glass provided according to the invention has a defined ratio of the proportions (in cat %) of particular cations of the glass components, which is described as the cation parameter K and determined as follows:

$$K=(\text{Ti-eq.}+SiO_2+(BO_{1.5})/2)/(\text{La-eq.})$$

[0029] For the glasses provided according to the invention, the following applies: $1.8<K\leq 2.8$.

[0030] This condition describes a composition range within which it is possible for the components that are advantageous for achievement of a high refractive index and high internal transmission to form an amorphous glass, i.e. without the formation of crystal phases. The challenge in such a high-refractive-index glass system is to obtain a stable glassy region alongside a low liquidus temperature. The condition according to the invention has allowed such a composition range to be found, which is described similarly to a miscibility gap in binary or ternary systems.

[0031] The glass here also has a temperature $T_{max}\leq 1330°$ C. and a n_d of 2.10.

[0032] In the cation parameter K, cations of the glass composition are classified—as published for example in: R. D. Shannon; Revised Effective Ionic Radii and Systematic Studies of Interatomic Distances in Halides and Chalcogenides; Acta Crystallographica. Section A 32, 751, 1976—into various groups according to their crystal ion radii:

- **[0033]** titanium equivalent (Ti-eq.) is formed from the sum total of the molar fractions of the cations of titanium (TiO_2), niobium ($NbO_{2.5}$), zirconium (ZrO_2), tungsten (WO_3), tantalum ($TaO_{2.5}$), aluminum ($AlO_{1.5}$), antimony ($SbO_{2.5}$) and arsenic ($AsO_{2.5}$), i.e. ions having a relatively small ionic radius of <100 μm;
- **[0034]** lanthanum equivalent (La-eq.) is formed from the sum total of the molar fractions of the cations of lanthanum ($LaO_{1.5}$), gadolinium ($GdO_{1.5}$), yttrium ($YO_{1.5}$) and ytterbium ($YbO_{1.5}$), i.e. ions having a relatively large ionic radius of >100 pm. La-eq. is the divisor of the cation parameter.

[0035] Also included in the condition is the molar cat % of the glass formers (SiO_2) and boron ($BO_{1.5}$), which are added to the cat % proportion of the titanium equivalents and together with Ti-eq. form the dividend of the cation parameter. Since it is possible in a glass composition when considering the molar fractions to replace a SiO_2 with a B_2O_3 with the refractive index remaining at about the same level, only half the cat % of $BO_{1.5}$ is included in the condition, i.e. $(BO_{1.5})/2$.

[0036] By selecting and mixing cations of different size in a defined ratio in accordance with the invention, it is possible to effectively counteract crystal formation.

[0037] The cation parameter K is according to the invention greater than 1.8 and max. 2.8. If the cation parameter is 1.8 or less, then T_{max} will be too high, with the result that internal transmission decreases through the ingress of refractory material and heightened reduction of polyvalent oxides brought about by the higher process temperatures that are necessary. In addition, the refractive index tends to fall when K is smaller, since lanthanum equivalents raise the refractive index less strongly than titanium equivalents. However, the cation parameter must not be too high either. A K value greater than 2.8 means that the glass contains too few lanthanum equivalents, which has an adverse effect on the tendency to crystallization and thus on T_{max}. Moreover, if the glass has an excessively high cation parameter K and thus too many titanium equivalents, it will have a greater tendency to oxidation and thus to discoloration on account of the higher content of polyvalent oxides such as TiO_2 and $NbO_{2.5}$. An advantageous lower limit for the cation parameter may be at least or more than 1.9 or at least 2.0. Some exemplary embodiments have a lower limit for the cation parameter of more than 2.0 or a lower limit of at least or more than 2.1 or at least or more than 2.2 or at least or more than 2.25 or at least or more than 2.3. Some embodiments provided according to the invention may have an upper limit for the cation parameter K of at most or less than 2.75 or at most or less than 2.7 or, for some exemplary variants, of at most or less than 2.6.

[0038] In addition, in a glass provided according to the invention the sum total of the glass components SiO_2 and B_2O_3 is at least 8.0 mol % and not more than 20.0 mol %, the proportion of B_2O_3 being >0 mol % and the proportion of SiO_2>0 mol %. The proportions of the glass components SiO_2 and B_2O_3 in mol % based on oxide can in each case be calculated from the composition stated in cat %. A glass provided according to the invention requires a sum total ($SiO_2+B_2O_3$) of at least 8.0 mol %, optionally of more than 8.0 mol %, of at least 9.0 mol % or at least 10.0 mol %, in order for it to be possible for a glassy composition to form in the melting process. However, the sum total should not exceed an upper limit of 20.0 mol %, since otherwise the glass will contain too small a proportion of glass components that increase the refractive index and the resulting refractive index will thus be too low. An advantageous upper limit for the sum total $SiO_2+B_2O_3$ may be <20 mol %. For some embodiments, the upper limit of the sum total $SiO_2+B_2O_3$ may be max. 19.0 mol % or max. 18.0 mol %. Some embodiments may also have an upper limit for the sum total of max. 17.0 mol % or max. 16.5 mol %. B_2O_3 may optionally amount to at least 1.0 mol % or at least 1.5 mol % or at least 2.0 mol % and/or optionally not more than 19.0 mol % or not more than 17.0 mol % or not more than 15.0 mol % or not more than 13.0 mol % or not more than 12.0 mol %. SiO_2 may optionally amount to at least 1.0 mol % or at least 2.0 mol % or at least 3.0 mol % and/or optionally not more than 19.0 mol % or not more than 18.0 mol % or not more than 16.0 mol % or not more than 15.0 mol %.

[0039] In addition, the glass provided according to the invention has a temperature T_{max} of ≤1330° C. T_{max} is a composition-dependent glass variable and indicates the temperature that is at least necessary in the melting process in order to generate a "blank" melt from the starting materials (for example raw materials, shards, etc.). A "blank" melt is present here when there are no remnants from melting—for example incompletely melted raw materials—and no crystals present in the melt. As explained in the introduction, the melting and refining temperatures should be as low as possible in order to avoid ingress of refractory material into the glass and coloration of the glass by polyvalent ions in a low oxidation state. This allows high internal transmission to be achieved. The requirement to achieve the highest-possible internal transmission means that the chosen melting and refining temperatures cannot be too high, consequently the melting temperature has an upper limit, hence the use also of the term "T_{max}" for the temperature described here. T_{max} is thus the lowest temperature at which a blank, crystal-free melt can still be produced. This relationship makes T_{max} a good measure for the liquidus temperature of the glass (see below).

[0040] In the context of the invention, the T_{max} of a glass composition is determined systematically on a laboratory scale in test series by melting the same glass from the starting components in small crucibles having a volume of in each case 20 ml at different maximum temperatures, with temperature increments of 10° C. chosen. Starting with the lowest temperature up to the highest temperature, the melting result is then visually evaluated in respect of whether a blank melt has been obtained or whether there are still remnants and/or crystals present in the glass.

[0041] The T_{max} value determined for a composition in this way is reproducible even with laboratory melts of larger volume (e.g. 1 litre). Moreover, further experiments have shown that the temperature T_{max} is only slightly above the liquidus temperature of the glass. It was inferred that the temperature T_{max}, which can be determined in an easily operated laboratory procedure, is a good measure for the liquidus temperature of the glass, which is not determined exactly here.

[0042] In some embodiments, T_{max} is less than 1330° C., for example not more than 1320° C., optionally not more than 1310° C., optionally not more than 1300° C. Some embodiments have a T_{max} of not more than 1290° C. or not more than 1280° C.

[0043] In addition, a glass provided according to the invention has a refractive index n_d of more than 2.10, which makes it possible for the system, for example a pair of AR eyeglasses, to achieve an advantageously greater FoV.

[0044] In some embodiments, the refractive index n_d is more than 2.100, optionally at least 2.110, optionally at least 2.115, optionally at least 2.120, optionally at least 2.125 or optionally at least 2.130 or at least 2.133. An exemplary upper limit for n_d may be 2.20 or 2.200 or 2.195 or 2.190 or 2.189. Overall, the refractive index can thus be within a range of from 2.10 to 2.20. The refractive index n_d is known to those skilled in the art and refers in particular to the refractive index at a wavelength of about 587.6 nm (wavelength of the d line of helium). Those skilled in the art will know how the refractive index n_d can be determined.

[0045] Optionally, the refractive index is determined with a refractometer, in particular with a V-block refractometer. In this case, samples having a square or approximately square base area (for example having dimensions of about 20 mm×20 mm×5 mm) may in particular be used. In the measurement with a V-block refractometer, the samples are generally placed in a V-shaped block prism having a known refractive index. The refraction of an incident light beam depends on the difference between the refractive index of the sample and the refractive index of the V-block prism, thereby allowing the refractive index of the sample to be determined. The measurement is optionally carried out at a temperature of 22° C.

[0046] In the context of the invention it has been possible to provide an optical glass having a refractive index n_d of more than 2.10 and a low temperature T_{max}, that is to say a low liquidus temperature, making it possible to provide a glass having high internal transmission.

[0047] An exemplary embodiment provided according to the invention has an internal transmission of at least 75%, at least 79%, at least 82% or at least 85% or at least 87% or at least 88% or at least 90% or at least 92% or at least 93% or at least 94% or at least 95% or at least 97%, measured at a wavelength of 460 nm and a sample thickness of 10 mm. When the glass is serving as a waveguide, the color impression is not distorted in the image that is generated in, for example, AR eyeglasses.

[0048] The internal transmission or degree of internal transmission can be measured using customary methods known to those skilled in the art, for example according to DIN 5036-1:1978. In this description, stated values for the internal transmission refer to a wavelength of 460 nm and a sample thickness of 10 mm. Stating a "sample thickness" does not mean that the glass has this thickness, but merely states the thickness to which the stated internal transmission refers.

[0049] Unless otherwise stated or obvious to those skilled in the art, measurements described herein are carried out at 20° C. and air pressure of 101.3 kPa.

[0050] In some embodiments provided according to the invention, the density of the glass is optionally <5.3 g/cm^3, optionally <5.2 g/cm^3 or <5.1 g/cm^3 or <5.0 g/cm^3.

[0051] In some embodiments provided according to the invention, the glasses have a low density in relation to a high refractive index, which allows weight savings to be made in optical components, for example in a pair of AR eyeglasses. This can be advantageous when the numerical value for the ratio $(n_d)^2$/density is more than 0.85, optionally more than 0.87, optionally more than 0.89, optionally more than 0.90 and/or optionally more than 0.99, optionally less than 0.98, optionally less than 0.97.

[0052] In some embodiments provided according to the invention, the glass has an Abbe number, i.e. dispersion (ν_d), of more than 18.5. Optionally, the dispersion is greater than 18.9, more optionally greater than 19.2 and/or more optionally greater than 19.5 and/or less than 30.0 or less than 25.0 or less than 24.0. ν_d is calculated in known manner, by determining the refraction values n_d (at about 587.6 nm), n_F (at about 486 nm) and n_C (at about 656 nm) using a refractometer and relating them to one another: $\nu_d=(n_d-1)/(n_F-n_C)$.

[0053] In some embodiments, the glass has a glass transition temperature T_g of 600° C. to 800° C. Optionally, T_g may be more than 670° C., more than 700° C., optionally more than 720° C. A higher T_g can be advantageous in respect of stability to crystallization since this means that the difference in temperature from T_{max} is lower and the glass

achieves a stable glassy state more rapidly. The glasses can however still readily undergo heat-forming and processing.

[0054] The average coefficient of thermal expansion (CTE) in the 20 to 300° C. temperature range should likewise not be too high, optionally in the range from 8.0 to 12.0 ppm/K, in the range from 8.3 to 11.5 ppm/K, optionally in the range from 8.5 to 11.0 ppm/K. The CTE is determined in accordance with DIN ISO 7991:1987.

[0055] The glass provided according to the invention contains titanium, niobium and lanthanum. Niobium-containing glasses are reputed to exhibit poorer internal transmission at the UV end of the visible range of the spectrum and, on account of the titanium content, to have a pronounced tendency to interfacial crystallization. These disadvantages to not occur with the lass described herein or occur only to a controllable degree.

[0056] Described below are the glass components that form the titanium equivalents (Ti-eq.) group:

[0057] The content of titanium (TiO_2) in the glass may be at least 32.0 cat %, optionally at least 34.0 cat % or at least 35.0 cat %. In some embodiments the content is even at least 37.0 cat % or at least 38.0 cat %. Some embodiments may even contain at least 39 cat % of TiO_2. The content of TiO_2 may optionally be limited to not more than 52.0 cat %, not more than 50.0 cat %, not more than 49.0 cat % or not more than 48.0 cat % or not more than 47.0 cat %. In the glasses provided according to the invention, the component TiO_2 takes on the role of glass formation and can therefore be described as an imperfect glass former. An excessively high TiO_2 content would cause a sharp reduction in the Abbe number.

[0058] The proportion of niobium ($NbO_{2.5}$) in the glass may be at least 3.0 cat %, optionally at least 4.0 cat %, optionally at least 4.5 cat %, optionally at least 5.0 cat % or at least 6.0 cat %. The content of $NbO_{2.5}$ may optionally be limited to not more than 15.0 cat %, not more than 13.0 cat %, not more than 11.0 cat % or not more than 10.0 cat %. Some embodiments may even contain max. 9.0 cat %. Alongside TiO_2 and $LaO_{1.5}$, $NbO_{2.5}$ contributes to a high refractive index. However, excessively high $NbO_{2.5}$ contents are disadvantageous in this glass system and result in increased crystallization.

[0059] The proportion of zirconium (ZrO_2) in the glass may be 0 to 11.0 cat %. There may be present in the glass at least 1.0 cat % or at least 2.0 cat %, optionally at least 3.0 cat % or at least 4.0 cat %, of ZrO_2. ZrO_2 can contribute to setting the cation parameter such that a glassy region with correspondingly low T_{max} is achieved for the glass system. The content of ZrO_2 may optionally be limited to not more than 11.0 cat %, not more than 10.0 cat %, not more than 9.0 cat % or not more than 8.0 cat %. Some embodiments may even contain max. 7.0 cat %. ZrO_2 contributes to achieving the high refractive index, but at high amounts it also increases the tendency of the glass to crystallization, consequently its content is optionally limited. ZrO_2-free variants are possible.

[0060] Tungsten (WO_3) is an optional component of the glass. WO_3 may be present in the glass in a content of max. 5.0 cat %, optionally max. 3.0 cat %, optionally max. 2 cat % or max. 1.5 cat % or max. 1 cat % or max. 0.7 cat %. When this component is present, a lower limit may be 0.1 cat %, optionally 0.3 cat %. WO_3-free variants are possible and advantageous.

[0061] Tantalum ($TaO_{2.5}$) is an optional component of the glass. $TaO_{2.5}$ may be present in the glass in a content of max. 5.0 cat %, optionally max. 3.0 cat %, optionally max. 2.0 cat % or max. 1.0 cat % or max. 0.7 cat %. When this component is present, a lower limit may be 0.1 cat %, optionally 0.3 cat %. $TaO_{2.5}$-free variants are also possible and may be advantageous.

[0062] Aluminum ($AlO_{1.5}$) is an optional component of the glass that can contribute to the chemical resistance, but also to the refractive index of the glass. Its content may be from 0 to 5.0 cat % or up to 3.0 cat % or up to 2.0 cat % or up to 1.0 cat %. When $AlO_{1.5}$ is present, it may be present in a proportion of at least 0.1 cat % or at least 0.5 cat %. Some embodiments are free of $AlO_{1.5}$.

[0063] Antimony ($SbO_{2.5}$) and arsenic ($AsO_{2.5}$) are optional components and may be present in the glass in each case and independently of one another in a content of max. 0.5 cat %, optionally max. 0.3 cat % or max. 0.1 cat % or max. 0.05 cat %. When at least one of these components is present in the glass, 0.005 cat % may be a lower limit in each case. $SbO_{2.5}$- and/or $AsO_{2.5}$-free variants are possible. Since the melts of the glasses provided according to the invention have low thickness, the use of classical refining agents to reduce bubble formation can be dispensed with. Vacuum refining may optionally be employed. $SbO_{2.5}$ and/or $AsO_{2.5}$ may however be added to the mixture in order to keep the glass melt in an oxidizing state at high melting and refining temperatures so that polyvalent ions, especially titanium and niobium ions, are not present in their respective lower oxidation states, with the result that the internal transmission of the glass produced is improved.

[0064] It may be advantageous when the total proportion of titanium equivalents (Ti-eq.) in the glass, i.e. the sum total of TiO_2+$NbO_{2.5}$+ZrO_2+WO_3+$AlO_{1.5}$+$TaO_{2.5}$+$AsO_{2.5}$+$SbO_{2.5}$, is at least 43.0 cat % or at least 44.0 cat %. In some embodiments, the sum total may be at least 45.0 cat % or at least 46.0 cat %, optionally at least 47.0 cat %, optionally at least 49.0 cat % or at least 50.0 cat % and/or not more than 63.0 cat %, optionally not more than 61.0%, optionally not more than 59.0% or not more than 58.0%. An excessively high amount of titanium equivalent can result in crystallization and a high T_{max}. The same applies to an excessively low amount.

[0065] In some embodiments provided according to the invention, the feature titanium equivalent is formed from the sum total of the molar fractions of the cations of titanium (TiO_2), niobium ($NbO_{2.5}$), zirconium (ZrO_2), antimony ($SbO_{2.5}$) and arsenic ($AsO_{2.5}$), with the upper limits and/or lower limits stated above for the total proportion of titanium equivalents (Ti-eq.) accordingly applying. It is self-evident that the glasses in such embodiments are essentially free of WO_3, $AlO_{1.5}$ and $TaO_{2.5}$.

[0066] In some embodiments, the feature titanium equivalent is formed from the sum total of the molar fractions of the cations of titanium (TiO_2), niobium ($NbO_{2.5}$) and zirconium (ZrO_2), with the upper limits and/or lower limits stated above for the total proportion of titanium equivalents (Ti-eq.) accordingly applying. It is self-evident that the glasses in such embodiments are essentially free of WO_3, $AlO_{1.5}$, $TaO_{2.5}$, $AsO_{2.5}$ and $SbO_{2.5}$.

[0067] In some embodiments, the following condition is satisfied: content of TiO_2 (in cat %) >content of $NbO_{2.5}$ (in cat %)>content of ZrO_2 (in cat %).

[0068] Described below are the glass components forming the lanthanum equivalents (La-eq.) group:

[0069] The content of lanthanum ($LaO_{1.5}$) in the glass may be at least 13.0 cat %, optionally at least 15.0 cat % or at least 16.0 cat %. In some embodiments the content is even at least 17.0 cat % or at least 18.0 cat %. In some embodiments the content is even at least 19.0 cat % or at least 20 cat %. The content of $LaO_{1.5}$ may optionally be limited to not more than 30.0 cat % or not more than 29.0 cat %. Some embodiments may have a $LaO_{1.5}$ content of not more than 28.0 cat %, not more than 26.0 cat %, not more than 25.0 cat % or not more than 24.0 cat % or not more than 23.0 cat %. Alongside TiO_2 and $NbO_{2.5}$, $LaO_{1.5}$ contributes to a high refractive index. Excessively high contents of $LaO_{1.5}$ contribute to increased devitrification and thus to an increase in T_{max}.

[0070] The proportion of gadolinium ($GdO_{1.5}$) in the glass may be 0 to 10.0 cat %. When it is present, the proportion may be at least 1.0 cat %, optionally at least 2.0 cat % or at least 3.0 cat %. The content of $GdO_{1.5}$ may optionally be limited to not more than 10.0 cat %, not more than 9.0 cat %, not more than 8.0 cat % or not more than 7.0 cat %. Some embodiments may also contain max. 6.0 cat % or max. 5.0 cat % of $GdO_{1.5}$.

[0071] Yttrium ($YO_{1.5}$) is an optional component of the glass and may be present in the glass in a content of max. 5.0 cat %, optionally max. 3.0 cat %, optionally max. 2.0 cat % or max. 1.5 cat % or max. 1.0 cat %. When this component is present, a lower limit may be 0.1 cat %, optionally 0.3 cat %. $YO_{1.5}$-free variants are possible.

[0072] Ytterbium ($YbO_{1.5}$) is an optional component of the glass and may be present in the glass in a content of max. 5.0 cat %, optionally max. 3.0 cat %, optionally max. 2 cat % or max. 1.5 cat % or max. 1.0 cat %. When this component is present, a lower limit is advantageously 0.1 cat %, optionally 0.3 cat %. $YO_{1.5}$-free variants are possible and may be advantageous.

[0073] It may be advantageous when the total proportion of lanthanum equivalents (La-eq.) in the glass, i.e. the sum total $LaO_{1.5}$+$GdO_{1.5}$+$YO_{1.5}$+$YbO_{1.5}$ in the glass is at least 21.0 cat %, optionally at least 22.0 cat %, optionally at least 23.0 cat % or at least 24.0 cat % and/or not more than 35.0 cat %, not more than 33.0 cat %, not more than 31.0 cat %. Some embodiments may also contain not more than 30.0 cat %, optionally not more than 29.0 cat %, optionally not more than 28.0 cat % or, in some embodiments, not more than 27.0 cat %, of lanthanum equivalents. An excessively high amount of lanthanum equivalent can result in crystallization and a high T_{max}. The same applies to an excessively low amount.

[0074] In some embodiments, the feature lanthanum equivalent is formed from the sum total of the molar fractions of the cations of lanthanum ($LaO_{1.5}$), gadolinium ($GdO_{1.5}$) and yttrium ($YO_{1.5}$), with the upper limits and/or lower limits stated above for the total proportion of lanthanum equivalents (La-eq.) accordingly applying. It is self-evident that the glasses in such embodiments are essentially free of $YbO_{1.5}$.

[0075] In some embodiments, the following condition is satisfied: content of $LaO_{1.5}$ (in cat %)>content of $GdO_{1.5}$ (in cat %)>content of $YO_{1.5}$ (in cat %).

[0076] In some embodiments, the proportion of the components TiO_2 and $LaO_{1.5}$ in the glass is at least 53.0 cat %, optionally at least 55.0 cat %, optionally at least 57.0 cat %, optionally at least 59.0 cat % and/or not more than 70.0 cat %, optionally not more than 69.0 cat % or not more than 68 cat %.

[0077] In some embodiments, the proportion of the components TiO_2, $LaO_{1.5}$ and $NbO_{2.5}$ is at least 60.0 cat %, optionally at least 63.0 cat %, optionally at least 65.0 cat %, optionally at least 67.0 cat % and/or not more than 80.0 cat %, optionally not more than 77 cat % or not more than 75 cat %, optionally not more than 73.0 cat %.

[0078] For the optical glass it may be advantageous when the sum total (Ti-eq.+La-eq.) in the glass is at least 72.0 cat %, optionally at least 73.0 cat %, optionally at least 74.0 cat % and/or not more than 85.0 cat %, optionally not more than 84.0 cat %, optionally not more than 83.0 cat %. Some embodiments also have a lower limit for the sum total (Ti-eq.+La-eq.) of at least 75.0 cat % or at least 76.0 cat %. The higher the sum total, the higher the refractive index of the glass. However, as the sum total increases, so it also becomes more difficult to provide a glass that is stable to crystallization and has a high T_{max} and accordingly high internal transmission.

[0079] Silicon (SiO_2) is a glass former. The component contributes to the chemical resistance. If it is used in very large amounts, the refractive index values of the invention cannot be achieved. According to the invention, the glass contains SiO_2 in a proportion of >0 cat %. Optionally, the glass contains at least 1.0 cat %, at least 2.0 cat % or at least 3.0 cat %. Some embodiments may also contain at least 4.0 cat % or at least 5.0 cat % of SiO_2. The SiO_2 content may be limited to less than 20.0 cat %, max. 18.0 cat % or max. 16.0 cat % or max. 14.0 cat % or max. 13.0 cat % or max. 12.0 cat %.

[0080] Boron ($BO_{1.5}$) likewise acts as a glass former. In the glass system provided according to the invention it contributes to the lowering of temperature T_{max}. According to the invention, the glass contains $BO_{1.5}$ in a proportion of >0 cat %. Optionally, the glass contains at least 1.0 cat %, at least 2.0 cat % or at least 3.0 cat %. Some embodiments may also contain at least 4.0 cat % or at least 5.0 cat % or at least 6.0 cat % of $BO_{1.5}$. The $BO_{1.5}$ content may be limited to less than 20.0 cat %, max. 19.0 cat % or max. 18.0 cat %. Some embodiments contain $BO_{1.5}$ in a proportion of max. 17.0 cat % or max. 16.0 cat % or max. 14.0 cat % or max. 12.0 cat % or max. 11.0 cat %.

[0081] With respect to the proportions of the components SiO_2 and $BO_{1.5}$, it should be noted that the proportions are to be selected such that the condition of 8.0 mol %≤(SiO_2+B_2O_3)≤20.0 mol % is satisfied. Further exemplary upper limits and lower limits for this feature have already been stated hereinabove.

[0082] The glass may comprise barium (BaO). The content of BaO is in some embodiments restricted to not more than 6.5 cat %, not more than 6.0 cat %, in some embodiments to not more than 5.5 cat %, since excessively high proportions result in undesired crystallization. When BaO is present in the glass, this component may amount to at least 0.1 cat %, at least 0.2 cat %, at least 0.5 cat %, or at least 1.0 cat %, at least 2.0 cat % or at least 3.0 cat %. The presence of BaO in the glass can be helpful in ensuring the viscosity is higher and steeper in the high-viscosity range from approx. 10^6 dPas to 10^{14} dPas. BaO-free variants are possible.

[0083] Zinc (ZnO), magnesium (MgO), calcium (CaO) and/or strontium (SrO) may optionally be used in the glass.

They lower the melting temperature and stabilize the glass against crystallization without reducing its chemical resistance to the degree brought about by alkali metal oxides. The content of ZnO may here be from 0 to 5.0 cat %, up to max. 4.0 cat % or up to max. 3.0 cat % or up to max. 2.0 cat % or up to max. 1.0 cat %. Some embodiments are free of ZnO. The content of MgO may be from 0 to 2.0 cat % or up to max. 1.0 cat %. Some embodiments are free of MgO. The content of CaO may be from 0 to 2.0 cat % or up to max. 1.0 cat %. Some embodiments are free of CaO. The content of SrO may be from 0 to 2.0 cat % or up to max. 1.0 cat %. Some embodiments are free of SrO. For the components mentioned, an exemplary lower limit may in each case be at least 0.1 cat % or at least 0.3 cat % or at least 0.5 cat %.

[0084] Alkali metal oxides, such as $LiO_{0.5}$, $NaO_{0.5}$, $KO_{0.5}$, $RbO_{0.5}$, $CsO_{0.5}$, may be present in the glass in a proportion for the individual components, in a proportion for the sum total thereof, of max. 2 cat %, max. 1 cat %, optionally max. 0.5 cat %. Small amounts of at least 0.1 cat % or at least 0.2 cat % (for the individual components or optionally for the sum total thereof) may be advantageous for the meltability of the glass. However, since these components lower the refractive index, there is an upper limit on the content thereof. Some embodiments are free of $LiO_{0.5}$ and/or $NaO_{0.5}$ and/or $KO_{0.5}$ and/or $RbO_{0.5}$ and/or $CsO_{0.5}$, optionally free of alkali metal oxides.

[0085] Tin oxide (SnO_2) shows only very low or no activity as a refining agent in the glass system provided according to the invention. It may however be present as a glass component in a proportion of max. 2 cat % or max. 1 cat % or max. 0.5 cat %. Optionally, the glass is SnO_2-free.

[0086] Sulfate (SO_3) may be present in a small proportion in the glass in order to stabilize higher oxidation states in polyvalent ions. When it is present, the proportion is at least 0.01 cat %. Higher proportions of sulfate increase the risk of pronounced bubble formation in the glass and the risk of platinum getting into the glass. The sulfate content may therefore be max. 0.5 cat %, optionally max. 0.1 cat %, optionally max. 0.05 cat %. Optionally, the glass is SO_3-free.

[0087] The glass may contain small amounts of hafnium (HfO_2), optionally max. 0.1 cat % or max. 0.05 cat %. It is generally not actively added but gets into the glass with the component ZrO_2 via the raw material. If using very pure ZrO_2 raw material, the glass may be HfO_2-free.

[0088] The optical glass may comprise fluorine (F). Embodiments may contain max. 1 cat %, optionally max. 0.5 cat %, optionally max. 0.1 cat %, of this component. Some embodiments are free of F.

[0089] In some embodiments, the glass includes the following components in cat %:

SiO_2	>0 to <20.0
$BO_{1.5}$	>0 to <20.0
TiO_2	32.0 to 52.0
$NbO_{2.5}$	3.0 to 15.0
ZrO_2	0 to 11.0
WO_3	0 to 5.0
$TaO_{2.5}$	0 to 5.0
$AlO_{1.5}$	0 to 5.0
$SbO_{2.5}$	0 to 0.5
$AsO_{2.5}$	0 to 0.5
$LaO_{1.5}$	13.0 to 30.0
$GdO_{1.5}$	0 to 10.0
$YO_{1.5}$	0 to 5.0
$YbO_{1.5}$	0 to 5.0

[0090] In some embodiments, the glass includes the following components in cat %:

SiO_2	>0 to <20.0
$BO_{1.5}$	>0 to <20.0
TiO_2	32.0 to 52.0
$NbO_{2.5}$	4.0 to 15.0
ZrO_2	0 to 11.0
WO_3	0 to 5.0
$TaO_{2.5}$	0 to 5.0
$AlO_{1.5}$	0 to 5.0
$SbO_{2.5}$	0 to 0.5
$AsO_{2.5}$	0 to 0.5
$LaO_{1.5}$	13.0 to 28.0
$GdO_{1.5}$	0 to 10.0
$YO_{1.5}$	0 to 5.0
$YbO_{1.5}$	0 to 5.0

[0091] In some embodiments, the glass includes the following components in cat %:

SiO_2	2.0 to 14.0
$BO_{1.5}$	1.0 to 18.0
TiO_2	34.0 to 50.0
$NbO_{2.5}$	5.0 to 13.0
ZrO_2	2.0 to 8.0
WO_3	0 to 2.0
$TaO_{2.5}$	0 to 1.0
$AlO_{1.5}$	0 to 2.0
$SbO_{2.5}$	0 to 0.1
$AsO_{2.5}$	0 to 0.1
$LaO_{1.5}$	16.0 to 24.0
$GdO_{1.5}$	2.0 to 8.0
$YO_{1.5}$	0.3 to 2.0
BaO	0 to 6.5

[0092] In some embodiments the glass consists to an extent of at least 95.0 cat %, of at least 98.0 cat % or of at least 99.0 cat %, of the components described herein, especially of the components listed in the tables above. In some embodiments the glass essentially consists entirely of these components.

[0093] As already explained above, the addition of classical refining agents is not necessary, since the melt has low thickness at the temperatures necessary for melting. When refining agents such as $AsO_{2.5}$, $SbO_{2.5}$, SO_3 and/or Cl are nevertheless added, the content thereof can be significantly lowered, for example to <0.1 cat %. Pure physical refinement is moreover possible and may be advantageous. The glass may optionally include one or more of the following components having a refining effect in the stated proportions in cat %.

$SbO_{2.5}$	0.0 to 0.5
$AsO_{2.5}$	0.0 to 0.5
SO_3	0.0 to 0.5
Cl	0.0 to 0.5

[0094] In some embodiments the glass is essentially free of cations of bismuth ($BiG_{1.5}$) and/or lead (PbO). The addition of bismuth would increase the density of the glass

disproportionately. Moreover, bismuth ions undergo reduction to elemental bismuth even at relatively low temperatures in the region of 1000° C., imparting a strong grey coloration to the glass. PbO is likewise avoided because of its adverse effect on a low density. It is also one of the toxic components.

[0095] The high contents of niobium, titanium and lanthanum means that costly components such as tantalum and/or tungsten and/or ytterbium and/or germanium (GeO_2) are not necessary in the glass, or necessary only in small proportions, in order to obtain a glass having the desired high refractive index. Lithium is known for its aggressiveness towards ceramic bath and crucible materials and is therefore also where possible not used, or used only in small amounts.

[0096] Optionally, the glass is free of phosphate ($PO_{2.5}$), since this makes the melt significantly reducing and thus significantly increases the oxygen requirement of the melt, which in turn increases platinum consumption, resulting in coloration of the glass.

[0097] Optionally, the glass is—based on the respective cations—essentially free of one or more constituents selected from magnesium, cadmium, gallium, germanium, coloring components—for example cobalt, vanadium, chromium, molybdenum, copper, nickel—and combinations thereof. Components such as iron, manganese, selenium, tellurium and/or thallium may be present in small proportions in the glass, for example they may get into the glass as impurities. Particularly iron, selenium and tellurium, but also manganese can act as redox partners. It may however be advantageous when these components too are not specifically added to the glass either individually or in combination

[0098] When this description states that the glass is free of a component or does not contain a certain component, what this means is that said component may at most be present as an impurity in the glass. This means that it is not added in significant amounts. Not significant amounts are amounts according to the invention of less than 100 ppm, optionally less than 50 ppm or less than 10 ppm (m/m).

[0099] In some embodiments, the invention relates to a glass article that includes or consists of the described glass. The glass article can take different forms. Optionally, the article has the form

[0100] of a glass substrate, especially as a constituent of a stack of substrates for an optical component, especially in a pair of AR eyeglasses,

[0101] a wafer, especially having a maximum diameter of 5.0 cm to 50.0 cm or having a diameter between 0.7 cm and 50 cm, optionally between 3 cm and 45 cm, or between 5 cm and 40 cm,

[0102] a lens, especially a spherical lens, a prism or an asphere, and/or

[0103] an optical waveguide, especially a fibre or plate.

[0104] In a further aspect the invention relates to the use of a glass or glass article described herein in AR eyeglasses, metaoptics, wafer-level optics, optical wafer applications or classical optics. Alternatively or in addition, the glass or glass article described herein may be used as a wafer, lens, spherical lens or optical waveguide.

[0105] The glasses provided according to the invention may be produced by melting commercial raw materials. For example, it is possible to melt the glasses in a device as described in the as yet unpublished DE 102020120168.

Examples

[0106] The compositions shown in Tables 1 to 14 that follow were melted and their properties investigated: Tables 1 to 13 show exemplary embodiments provided according to the invention (examples 1 to 99) and Table 14 comparative examples (comparative examples A to G). In some of the glasses the internal transmission was determined. The internal transmission of example 31 is shown in FIG. **1**.

[0107] Compositions and Properties

TABLE 1

Cat %	1	2	3	4	5	6	7	8
$AlO_{1.5}$								
$BO_{1.5}$	11.88	11.88	11.88	17.35	13.95	10.43	6.76	2.96
BaO	3.75	4.95	4.95	4.92	5.01	5.11	5.21	5.31
CaO								
$GdO_{1.5}$	3.28	3.13	6.26	3.00	3.06	3.12	3.18	3.24
$KO_{0.5}$								
$LaO_{1.5}$	22.97	21.92	18.79	21.02	21.42	21.82	22.24	22.68
$NbO_{2.5}$	6.41	6.41	6.41	6.01	6.12	6.23	6.35	6.48
SiO_2	4.75	4.75	4.75	3.65	5.58	7.58	9.66	11.82
SrO								
TiO_2	42.70	42.70	42.70	40.04	40.78	41.55	42.36	43.19
$YO_{1.5}$								
ZnO								
ZrO_2	4.27	4.27	4.27	4.00	4.08	4.16	4.24	4.32
WO_3								
$TaO_{2.5}$								
$SbO_{2.5}$								
$AsO_{2.5}$								
Cation parameter	2.44	2.56	2.56	2.60	2.60	2.60	2.60	2.60
B_2O_3 [mol %]	7.64	7.58	7.58	11.37	8.98	6.58	4.19	1.80
SiO_2 [mol %]	6.11	6.06	6.06	4.79	7.18	9.57	11.97	14.36
$SiO_2 + B_2O_3$ [mol %]	13.75	13.64	13.64	16.16	16.16	16.15	16.16	16.16

TABLE 1-continued

Cat %	1	2	3	4	5	6	7	8
Properties								
T_{max} [° C.]	1280	1280	1300	1300	1300	1300	1300	1320
n_d	2.161	2.156	2.153	2.135	2.137	2.139	2.141	2.143
v_d	20.4	20.5	20.3	20.8	20.8	20.8	20.8	20.9
Density [g/cm^3]	4.98	4.96	4.94	4.90	4.91	4.94	4.94	4.96
n_d^2/Density	0.937	0.936	0.939	0.931	0.930	0.927	0.927	0.926

TABLE 2

Cat %	9	10	11	12	13	14	15	16
$AlO_{1.5}$			0.61					
$BO_{1.5}$	10.43	10.43	10.43	10.43	10.43	10.43	10.43	10.43
BaO	4.95	5.16	5.16	4.64	4.64	5.16	5.16	5.16
CaO					0.52			
$GdO_{1.5}$	3.02	3.15	3.15	3.15	3.15	3.15	3.15	3.15
$KO_{0.5}$								
$LaO_{1.5}$	21.13	22.03	22.03	22.03	22.03	21.02	22.03	22.03
$NbO_{2.5}$	6.35	6.20	6.20	6.20	6.20	6.20	6.20	10.33
SiO_2	7.58	7.58	6.98	7.58	7.58	7.58	7.58	7.58
SrO				0.52				
TiO_2	42.31	41.33	41.33	41.33	41.33	41.33	40.29	37.19
$YO_{1.5}$						1.01		
ZnO							1.03	
ZrO_2	4.23	4.13	4.13	4.13	4.13	4.13	4.13	4.13
WO_3								
$TaO_{2.5}$								
$SbO_{2.5}$								
$AsO_{2.5}$								
Cation parameter	2.72	2.56	2.56	2.56	2.56	2.56	2.52	2.56
B_2O_3 [mol %]	6.55	6.59	6.62	6.59	6.59	6.59	6.59	6.77
SiO_2 [mol %]	9.53	9.59	8.85	9.59	9.59	9.59	9.59	9.84
$SiO_2 + B_2O_3$ [mol %]	16.08	16.18	15.47	16.18	16.18	16.18	16.18	16.61
Properties								
T_{max} [° C.]	1320	1280	1280	1280	1280	1280	1280	1280
n_d	2.143	2.138	2.137	2.136	2.139	2.139	2.133	2.135
v_d	20.6	20.9	20.9	20.9	20.8	20.9	21.1	21.1
Density [g/cm^3]	4.90	4.93	4.94	4.94	4.93	4.93	4.96	4.96
n_d^2/Density	0.937	0.926	0.925	0.924	0.929	0.928	0.916	0.918

TABLE 3

Cat %	17	18	19	20	21	22	23	24
$AlO_{1.5}$								
$BO_{1.5}$	10.43	10.43	6.76	10.43	10.43	10.43	9.52	9.52
BaO	5.16	5.16	5.26	5.19	5.16	5.19	5.31	5.23
CaO								
$GdO_{1.5}$	3.15	3.15	3.21	3.17	3.15	3.17	3.24	3.19
$KO_{0.5}$								
$LaO_{1.5}$	22.03	21.02	21.43	21.15	21.02	21.15	21.91	21.57
$NbO_{2.5}$	6.20	6.20	6.32	6.18	6.20	6.18	6.42	6.48
SiO_2	7.58	7.58	9.66	7.58	7.58	7.58	5.71	5.71
SrO								
TiO_2	38.74	40.29	41.07	41.18	40.81	40.66	42.82	43.20
$YO_{1.5}$		1.01	1.03	1.01	1.01	1.01	0.78	0.77
ZnO		1.03	1.05		0.52	0.51		
ZrO_2	6.72	4.13	4.21	4.12	4.13	4.12	4.28	4.32
WO_3								
$TaO_{2.5}$								
$SbO_{2.5}$								
$AsO_{2.5}$								

TABLE 3-continued

Cat %	17	18	19	20	21	22	23	24
Cation parameter	2.56	2.52	2.52	2.54	2.54	2.52	2.47	2.53
B_2O_3 [mol %]	6.59	6.59	4.19	6.60	6.59	6.60	6.02	6.01
SiO_2 [mol %]	9.59	9.59	11.98	9.59	9.59	9.59	7.23	7.21
$SiO_2 + B_2O_3$ [mol %]	16.18	16.18	16.17	16.19	16.18	16.19	13.25	13.22
Properties								
T_{max} [° C.]	1280	1300	1320	1300	1300	1300	1280	1290
n_d	2.129	2.134	2.136	2.138	2.136	2.136	2.157	2.158
v_d	21.5	21.1	21.1	20.9	21.0	21.0	20.6	20.5
Density [g/cm^3]	4.98	4.94	4.96	4.92	4.93	4.94	4.98	4.98
n_d^2/Density	0.911	0.922	0.921	0.930	0.927	0.923	0.934	0.935

TABLE 4

Cat %	25	26	27	28	29	30	31	32
$AlO_{1.5}$								
$BO_{1.5}$	9.52	9.52	7.41	7.41	7.41	7.41	10.43	10.43
BaO	5.15	5.07	5.37	5.29	5.21	5.12	5.16	5.19
CaO								
$GdO_{1.5}$	3.14	3.09	3.28	3.23	3.18	3.13	3.15	3.17
$KO_{0.5}$								
$LaO_{1.5}$	21.24	20.91	22.15	21.81	21.48	21.14	21.27	21.41
$NbO_{2.5}$	6.54	6.59	6.78	6.84	6.90	6.96	6.20	6.18
SiO_2	5.71	5.71	4.48	4.48	4.48	4.48	7.58	7.58
SrO								
TiO_2	43.58	43.96	45.22	45.60	45.99	46.37	40.81	40.66
$YO_{1.5}$	0.75	0.74	0.79	0.77	0.76	0.75	0.76	0.76
ZnO							0.52	0.51
ZrO_2	4.36	4.40	4.52	4.56	4.60	4.64	4.13	4.12
WO_3								
$TaO_{2.5}$								
$SbO_{2.5}$								
$AsO_{2.5}$							0.01	0.01
Cation parameter	2.58	2.64	2.47	2.53	2.58	2.64	2.54	2.52
B_2O_3 [mol %]	6.00	5.98	4.65	4.64	4.63	4.62	6.59	6.60
SiO_2 [mol %]	7.20	7.18	5.61	5.60	5.59	5.58	9.59	9.59
$SiO_2 + B_2O_3$ [mol %]	13.20	13.16	10.26	10.24	10.22	10.20	16.18	16.19
Properties								
T_{max} [° C.]	1300	1290	1320	1310	1310	1290	1280	1280
n_d	2.160	2.162	2.178	2.181	2.182	2.184	2.136	2.135
v_d	20.4	20.3	20.1	20.0	19.9	19.8	21.0	21.0
Density [g/cm^3]	4.96	4.94	5.03	5.02	5.01	4.99	4.94	4.94
n_d^2/Density	0.942	0.946	0.943	0.948	0.951	0.955	0.924	0.924

TABLE 5

Cat %	33	34	35	36	37	38	39	40
$AlO_{1.5}$								
$BO_{1.5}$	10.43	10.43	10.43	10.43	10.43	10.43	10.43	9.52
BaO	5.11	5.16	5.16	4.64	4.64	4.64	5.16	5.18
CaO					0.52			
$GdO_{1.5}$	3.12	3.15	3.15	3.15	3.15	3.15	3.15	3.16
$KO_{0.5}$						0.52		
$LaO_{1.5}$	21.07	21.27	21.27	21.27	21.27	21.27	21.27	21.37
$NbO_{2.5}$	6.23	6.20	6.20	6.20	6.20	6.20	6.20	6.23
SiO_2	7.58	7.58	7.58	7.58	7.58	7.58	7.58	8.10
SrO				0.52				
TiO_2	41.04	40.81	40.29	40.81	40.81	40.81	40.29	41.00
$YO_{1.5}$	0.75	0.76	0.76	0.76	0.76	0.76	0.76	0.76
ZnO	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52

TABLE 5-continued

Cat %	33	34	35	36	37	38	39	40
ZrO_2	4.16	4.13	4.13	4.13	4.13	4.13	4.13	4.15
WO_3			0.52					
$TaO_{2.5}$							0.52	
$SbO_{2.5}$								
$AsO_{2.5}$	0.01							
Cation parameter	2.58	2.54	2.54	2.54	2.54	2.54	2.54	2.54
B_2O_3 [mol %]	6.58	6.59	6.59	6.59	6.59	6.61	6.61	5.99
SiO_2 [mol %]	9.57	9.59	9.59	9.59	9.59	9.62	9.62	10.19
$SiO_2 + B_2O_3$ [mol %]	16.15	16.18	16.18	16.18	16.18	16.23	16.23	16.18
Properties								
T_{max} [° C.]	1280	1300	1300	1300	1300	1300	1300	1300
n_d	2.137	2.136	2.135	2.135	2.138	2.135	2.136	2.137
v_d	20.9	21.0	20.9	21.0	20.9	21.0	21.0	21.0
Density [g/cm^3]	4.92	4.94	4.95	4.93	4.93	4.90	4.97	4.94
n_d^2/Density	0.928	0.923	0.921	0.923	0.928	0.929	0.918	0.925

TABLE 6

Cat %	41	42	43	44	45	46	47	48
$AlO_{1.5}$								
$BO_{1.5}$	11.32	11.32	11.32	7.69	9.52	10.43	8.61	8.61
BaO	5.13	5.26	5.18	5.28	5.18	4.64	5.27	5.19
CaO						0.52		
$GdO_{1.5}$	3.13	3.21	3.16	3.22	3.40	3.15	3.22	3.17
$KO_{0.5}$								
$LaO_{1.5}$	21.17	21.70	21.37	21.78	22.98	21.27	21.75	21.41
$NbO_{2.5}$	6.17	6.36	6.42	6.54	6.06	6.20	6.79	6.84
SiO_2	7.08	4.72	4.72	6.73	7.62	7.58	3.83	3.83
SrO								
TiO_2	40.62	42.42	42.79	43.62	39.88	39.78	44.68	45.06
$YO_{1.5}$	0.75	0.77	0.76	0.77	0.82	0.76	0.77	0.76
ZnO	0.51				0.50	0.52	0.57	0.57
ZrO_2	4.11	4.24	4.28	4.36	4.04	4.13	4.52	4.56
WO_3						0.52		
$TaO_{2.5}$						0.52		
$SbO_{2.5}$								
$AsO_{2.5}$						0.01		
Cation parameter	2.54	2.47	2.53	2.53	2.29	2.54	2.49	2.55
B_2O_3 [mol %]	7.19	7.23	7.21	4.81	6.06	6.61	5.42	5.41
SiO_2 [mol %]	8.99	6.02	6.01	8.41	9.69	9.62	4.82	4.81
$SiO_2 + B_2O_3$ [mol %]	16.18	13.25	13.22	13.22	15.75	16.23	10.24	10.22
Properties								
T_{max} [° C.]	1300	1300	1310	1310	1320	1320	1320	1320
n_d	2.136	2.156	2.157	2.160	2.134	2.136	2.177	2.178
v_d	21.0	20.6	20.5	20.5	21.4	20.8	20.1	20.0
Density [g/cm^3]	4.93	4.97	4.96	4.98	5.00	4.92	5.03	5.02
n_d^2/Density	0.925	0.934	0.938	0.937	0.912	0.927	0.941	0.945

TABLE 7

Cat %	49	50	51	52	53	54	55	56
$AlO_{1.5}$								
$BO_{1.5}$	8.61	8.61	8.61	10.43	10.43	10.43	10.43	10.43
BaO	5.11	5.03	4.95	5.01	4.90	5.12	5.08	5.03
CaO								
$GdO_{1.5}$	3.12	3.07	3.02	3.06	2.99	3.13	3.10	3.07
$KO_{0.5}$								

TABLE 7-continued

Cat %	49	50	51	52	53	54	55	56
$LaO_{1.5}$	21.07	20.74	20.40	20.67	20.21	21.14	20.94	20.74
$NbO_{2.5}$	6.90	6.96	7.02	6.30	6.38	6.22	6.26	6.29
SiO_2	3.83	3.83	3.83	7.58	7.58	7.58	7.58	7.58
SrO								
TiO_2	45.43	45.81	46.19	41.48	42.01	40.96	41.18	41.41
$YO_{1.5}$	0.75	0.74	0.72	0.73	0.72	0.75	0.74	0.74
ZnO	0.58	0.58	0.58	0.53	0.53	0.52	0.52	0.52
ZrO_2	4.60	4.64	4.68	4.20	4.25	4.15	4.17	4.19
WO_3								
$TaO_{2.5}$								
$SbO_{2.5}$								
$AsO_{2.5}$								
Cation parameter	2.61	2.67	2.73	2.65	2.74	2.56	2.60	2.64
B_2O_3 [mol %]	5.40	5.39	5.38	6.57	6.55	6.59	6.58	6.57
SiO_2 [mol %]	4.80	4.79	4.78	9.55	9.52	9.58	9.57	9.55
$SiO_2 + B_2O_3$ [mol %]	10.20	10.18	10.16	16.12	16.07	16.17	16.15	16.12
Properties								
T_{max} [° C.]	1320	1320	1320	1320	1320	1300	1300	1300
n_d	2.180	2.182	2.184	2.139	2.142	2.137	2.138	2.139
v_d	19.9	19.8	19.7	20.8	20.6	20.9	20.9	20.8
Density [g/cm^3]	5.01	5.00	4.98	4.91	4.89	4.93	4.92	4.91
n_d^2/Density	0.949	0.953	0.957	0.932	0.938	0.927	0.929	0.931

TABLE 8

Cat %	57	58	59	60	61	62	63	64
$AlO_{1.5}$								
$BO_{1.5}$	10.43	8.80	8.80	8.80	8.80	10.43	10.43	8.80
BaO	4.98	5.05	5.01	4.96	4.91	5.08	5.03	4.99
CaO								
$GdO_{1.5}$	3.04	3.08	3.05	3.03	3.00	3.10	3.07	3.05
$KO_{0.5}$								
$LaO_{1.5}$	20.54	20.85	20.65	20.45	20.25	20.94	20.74	20.58
$NbO_{2.5}$	6.32	6.89	6.93	6.96	7.00	6.26	6.29	6.94
SiO_2	7.58	4.02	4.02	4.02	4.02	7.58	7.58	4.02
SrO								
TiO_2	41.63	45.39	45.62	45.84	46.07	41.18	41.41	45.69
$YO_{1.5}$	0.73	0.74	0.73	0.73	0.72	0.74	0.74	0.73
ZnO	0.53	0.57	0.58	0.58	0.58	0.52	0.52	0.58
ZrO_2	4.22	4.60	4.62	4.64	4.67	4.17	4.19	4.63
WO_3								
$TaO_{2.5}$								
$SbO_{2.5}$								
$AsO_{2.5}$						0.01	0.01	
Cation parameter	2.67	2.65	2.68	2.72	2.76	2.60	2.64	2.70
B_2O_3 [mol %]	6.56	5.51	5.50	5.50	5.49	6.58	6.57	5.50
SiO_2 [mol %]	9.54	5.03	5.02	5.02	5.01	9.57	9.55	5.02
$SiO_2 + B_2O_3$ [mol %]	16.10	10.54	10.52	10.52	10.50	16.15	16.12	10.52
Properties								
T_{max} [° C.]	1300	1300	1300	1300	1300	1320	1320	1320
n_d	2.140	2.179	2.180	2.181	2.182	2.139	2.139	2.180
v_d	20.7	19.9	19.8	19.8	19.7	20.9	20.8	19.8
Density [g/cm^3]	4.91	4.99	4.99	4.98	4.97	4.92	4.91	4.99
n_d^2/Density	0.934	0.950	0.953	0.955	0.957	0.930	0.931	0.953

TABLE 9

Cat %	65	66	67	68	69	70	71
$AlO_{1.5}$							
$BO_{1.5}$	8.80	10.96	6.58	10.43	10.43	10.43	10.43
BaO	5.46	4.93	5.05	5.16	5.16	5.16	5.20
CaO							
$GdO_{1.5}$	2.99	3.01	3.08	3.15	3.15	3.15	3.18
$KO_{0.5}$							
$LaO_{1.5}$	20.19	20.35	20.82	21.27	21.27	21.27	21.47
$NbO_{2.5}$	6.94	6.86	7.02	11.36	6.12	5.17	6.10
SiO_2	4.02	2.84	5.22	7.58	8.25	7.58	8.15
SrO							
TiO_2	45.69	45.17	46.22	35.64	40.29	40.81	40.64
$YO_{1.5}$	0.72	0.72	0.74	0.76	0.76	0.76	0.76
ZnO	0.58	0.57	0.59	0.52	0.51	0.52	
ZrO_2	4.63	4.57	4.68	4.13	4.08	4.13	4.06
WO_3						1.03	
$TaO_{2.5}$							
$SbO_{2.5}$							
$AsO_{2.5}$					0.01	0.01	0.01
Cation parameter	2.75	2.70	2.70	2.54	2.54	2.54	2.53
B_2O_3 [mol %]	5.48	6.94	4.07	6.81	6.59	6.55	6.60
SiO_2 [mol %]	5.01	3.59	6.46	9.91	10.42	9.52	10.31
$SiO_2 + B_2O_3$ [mol %]	10.49	10.53	10.53	16.72	17.01	16.07	16.91
Properties							
T_{max} [° C.]	1300	1320	1300	1300	1300	1310	1300
n_d	2.178	2.179	2.181	2.132	2.130	2.133	2.132
v_d	19.8	19.8	19.8	21.3	21.1	20.8	21.4
Density [g/cm^3]	4.98	4.98	4.99	4.97	4.92	4.92	4.94
n_d^2/Density	0.953	0.954	0.953	0.915	0.922	0.925	0.920

TABLE 10

Cat %	72	73	74	75	76	77	78	79
$AlO_{1.5}$								
$BO_{1.5}$	12.38	12.38	12.38	12.38	16.18	12.21	12.03	11.85
BaO								
CaO								
$GdO_{1.5}$	4.52	4.56	4.60	4.64	4.46	4.62	4.69	4.76
$KO_{0.5}$								
$LaO_{1.5}$	25.69	25.93	26.16	26.39	25.40	26.26	26.67	27.09
$NbO_{2.5}$	5.76	5.73	5.70	5.66	5.61	5.71	5.68	5.66
SiO_2	8.44	8.44	8.44	8.44	6.25	8.36	8.27	8.18
SrO								
TiO_2	37.94	37.72	37.50	37.28	36.96	36.66	36.47	36.29
$YO_{1.5}$	0.93	0.94	0.95	0.96	0.92	0.95	0.97	0.98
ZnO	0.48	0.48	0.47	0.47	0.47	0.48	0.47	0.47
ZrO_2	3.84	3.82	3.80	3.77	3.74	4.76	4.74	4.71
WO_3								
$TaO_{2.5}$								
$SbO_{2.5}$								
$AsO_{2.5}$								
Cation parameter	2.00	1.97	1.94	1.92	1.97	1.93	1.89	1.85
B_2O_3 [mol %]	8.22	8.23	8.24	8.26	10.97	8.12	8.02	7.92
SiO_2 [mol %]	11.20	11.22	11.24	11.26	8.48	11.12	11.03	10.94
$SiO_2 + B_2O_3$ [mol %]	19.42	19.45	19.48	19.52	19.45	19.24	19.05	18.86
Properties								
T_{max} [° C.]	1300	1300	1300	1300	1300	1300	1300	1300
n_d	2.136	2.135	2.135	2.134	2.133	2.134	2.135	2.134
v_d	21.6	21.6	21.7	21.8	21.6	21.9	21.8	21.6
Density [g/cm^3]	5.00	5.01	5.01	5.02	4.99	5.05	5.02	5.00
n_d^2/Density	0.912	0.910	0.910	0.907	0.912	0.902	0.908	0.911

TABLE 11

Cat %	80	81	82	83	84	85	86	87
$AlO_{1.5}$								
$BO_{1.5}$	11.68	11.85	11.94	12.21	11.68	11.85	12.03	10.52
BaO	1.66	1.63	1.60	1.57	3.11	3.06	3.01	5.15
CaO								
$GdO_{1.5}$	4.58	4.50	4.42	4.33	4.06	3.99	3.92	3.92
$KO_{0.5}$								
$LaO_{1.5}$	26.05	25.58	25.13	24.65	23.07	22.70	22.33	22.32
$NbO_{2.5}$	4.54	4.57	4.60	4.62	4.73	4.75	4.78	4.81
SiO_2	7.34	7.43	7.57	7.70	7.44	7.53	7.61	6.68
SrO								
TiO_2	37.95	38.22	38.50	38.67	39.60	39.79	39.97	40.22
$YO_{1.5}$	0.95	0.93	0.91	0.90	0.84	0.83	0.81	0.81
ZnO	0.48	0.48	0.48	0.49	0.50	0.50	0.50	0.51
ZrO_2	4.77	4.81	4.84	4.86	4.98	5.00	5.03	5.06
WO_3								
$TaO_{2.5}$								
$SbO_{2.5}$								
$AsO_{2.5}$								
Cation parameter	1.91	1.97	2.02	2.07	2.24	2.29	2.34	2.29
B_2O_3 [mol %]	7.67	7.77	7.81	7.96	7.50	7.60	7.71	6.67
SiO_2 [mol %]	9.65	9.74	9.89	10.05	9.56	9.66	9.75	8.48
$SiO_2 + B_2O_3$ [mol %]	17.32	17.51	17.70	18.01	17.06	17.26	17.46	15.15
Properties								
T_{max} [° C.]	1320	1320	1300	1300	1300	1300	1300	1300
n_d	2.134	2.134	2.134	2.134	2.134	2.134	2.134	2.134
v_d	21.9	21.8	21.7	21.6	21.4	21.4	21.3	21.4
Density [g/cm^3]	5.07	5.04	5.03	5.00	4.98	4.96	4.94	5.00
n_d^2/Density	0.898	0.904	0.905	0.911	0.914	0.918	0.922	0.911

TABLE 12

Cat %	88	89	90	91	92	93	94	95
$AlO_{1.5}$								
$BO_{1.5}$	10.79	10.96	11.14	11.23	11.68	12.65	9.71	11.85
BaO	5.07	4.99	4.91	4.83	3.11	3.00	5.02	4.82
CaO								
$GdO_{1.5}$	3.86	3.80	3.74	3.68	4.06	3.91	3.82	3.67
$KO_{0.5}$								
$LaO_{1.5}$	21.96	21.62	21.27	20.93	23.07	22.26	21.76	20.86
$NbO_{2.5}$	4.82	4.84	4.86	4.89	4.73	4.77	4.86	4.87
SiO_2	6.81	6.90	6.99	7.13	7.44	7.17	7.71	6.77
SrO								
TiO_2	40.31	40.50	40.69	40.89	39.60	39.92	40.70	40.76
$YO_{1.5}$	0.80	0.79	0.77	0.76	0.84	0.81	0.79	0.76
ZnO	0.51	0.51	0.51	0.51	0.50	0.50	0.51	0.51
ZrO_2	5.07	5.09	5.12	5.14	4.98	5.02	5.12	5.13
WO_3								
$TaO_{2.5}$								
$SbO_{2.5}$								
$AsO_{2.5}$					0.01	0.01	0.01	0.01
Cation parameter	2.34	2.40	2.45	2.51	2.24	2.34	2.40	2.51
B_2O_3 [mol %]	6.84	6.94	7.04	7.09	7.50	8.13	6.10	7.50
SiO_2 [mol %]	8.63	8.73	8.83	8.99	9.56	9.21	9.69	8.57
$SiO_2 + B_2O_3$ [mol %]	15.47	15.67	15.87	16.08	17.06	17.34	15.79	16.07
Properties								
T_{max} [° C.]	1300	1300	1300	1300	1300	1300	1300	1300
n_d	2.134	2.134	2.134	2.134	2.133	2.134	2.134	2.134
v_d	21.4	21.3	21.2	21.1	21.4	21.2	21.3	21.1

TABLE 12-continued

Cat %	88	89	90	91	92	93	94	95
Density [g/cm^3]	4.98	4.97	4.95	4.94	4.98	4.94	4.97	4.93
n_d^2/Density	0.914	0.916	0.920	0.922	0.914	0.922	0.916	0.924

TABLE 13

Cat %	96	97	98	99
$AlO_{1.5}$				
$BO_{1.5}$	12.73	12.38	12.21	11.83
BaO				4.77
CaO				
$GdO_{1.5}$	4.47	4.52	4.44	3.63
$KO_{0.5}$				
$LaO_{1.5}$	25.41	25.69	25.25	20.78
$NbO_{2.5}$	5.74	5.76	5.79	4.82
SiO_2	8.61	8.44	8.92	6.37
SrO				
TiO_2	37.80	37.94	38.13	41.60
$YO_{1.5}$	0.92	0.93	0.92	0.77
ZnO	0.48	0.48	0.48	0.53
ZrO_2	3.83	3.84	3.86	4.89
WO_3				
$TaO_{2.5}$				
$SbO_{2.5}$				
$AsO_{2.5}$				0.008
Cation parameter	2.02	2.00	2.05	2.12
B_2O_3 [mol %]	8.45	8.22	8.06	7.49
SiO_2 [mol %]	11.43	11.20	11.78	8.07
$SiO_2 + B_2O_3$ [mol %]	19.88	19.42	19.84	15.56
Properties				
T_{max} [°C]	1320	1300	1320	1280
n_d	2.134	2.136	2.135	2.134
ν_d	21.6	21.6	21.5	21.3
Density [g/cm^3]	4.98	5.00	4.97	4.95
n_d^2/Density	0.914	0.912	0.917	0.920

TABLE 14

Cat %	A	B	C	D	E	F	G
$AlO_{1.5}$							
$BO_{1.5}$				6.57	11.88	7.69	10.43
BaO	10.71	14.82	8.44	3.84	4.54	10.34	5.04
CaO							
$GdO_{1.5}$				4.00	2.87	2.57	3.08
$KO_{0.5}$							
$LaO_{1.5}$	15.29	21.18	22.56	19.62	20.09	17.14	20.81
$NbO_{2.5}$	5.54	4.64	5.09	9.61	6.71	6.62	21.98
SiO_2	12.50	12.50	12.50	13.42	4.75	6.25	7.58
SrO							
TiO_2	52.28	43.78	48.03	38.13	44.70	44.15	25.64
$YO_{1.5}$						0.82	0.74
ZnO							0.52
ZrO_2	3.69	3.09	3.39	4.81	4.47	4.42	4.19
WO_3							
$TaO_{2.5}$							
$SbO_{2.5}$							
$AsO_{2.5}$							
Cation parameter	4.84	3.02	3.06	2.93	2.90	3.18	2.62
B_2O_3 [mol %]				4.10	7.49	4.66	7.29
SiO_2 [mol %]	13.95	14.35	14.51	16.75	6.00	7.57	10.61
$SiO_2 + B_2O_3$ [mol %]	13.95	14.35	14.51	20.85	13.49	12.23	17.90
Properties							
T_{max} [° C.]	1370	1450	1350	1390	1380	1360	1350
n_d	2.154	2.107	2.149	2.121	2.166	2.142	2.125
ν_d	19.3	21.6	20.4	21.0	19.8	20.4	21.7
Density [g/cm^3]	4.70	4.95	4.91	4.84	4.90	4.90	5.03
n_d^2/Density	0.987	0.897	0.940	0.930	0.958	0.937	0.897

FIGURES

[0108] FIG. **1** shows an internal transmission spectrum of exemplary glass **31** from Table 1. It can be seen that this example exhibits at 460 nm an internal transmission T_i of more than 88% at a sample thickness of 10 mm. In addition, the transmission curve shows the advantageously steep fall from the visible region of the spectrum to the adjoining UV region.

[0109] FIG. **2** shows the relationship of the cation parameter K and T_{max} for exemplary embodiments and comparative examples from Tables 1 to 9 and 14. It can be seen that the glasses provided according to the invention from Tables 1 to 9 have a cation parameter in the range from above 2.0 and max. 2.8 and at the same time a T_{max} of in this case less than 1330° C., i.e. they have a relatively low liquidus temperature. In addition, all examples have a refractive index n_d of more than 2.10. Thus, what has been found in the context of the invention is a stable glassy range alongside a low liquidus temperature in a high-refractive-index glass system.

[0110] FIG. **3** shows the relationship of the cation parameter K and T_{max} for exemplary embodiments and comparative examples from the tables. In addition to the exemplary embodiments shown in FIG. **2**, the exemplary embodiments of Tables 10 to 12 are depicted. It can be seen that even examples having a cation parameter in the range from above 1.8 to 2.0 alongside a refractive index of more than 2.10 may at the same time have a T_{max} here of less than 1330° C., i.e. they may have a relatively low liquidus temperature.

[0111] In the context of the invention, it was found that glasses having a cation parameter of more than 2.0 have a lower tendency to crystallization than glasses having a cation parameter of max. 2.0, which have a stronger tendency to crystallization. A higher tendency to crystallization narrows the process window during production, making production more laborious for such glasses. In the process window the temperature of the melt is above T_{max}. However, in order that the viscosity is not too low and for it to still be possible for the glass to be handled, for example with regard to hot forming, the chosen temperature cannot be too high. A further consequence of an increased tendency to crystallization may be, for example, that it is possible to produce only smaller glass articles.

[0112] While this invention has been described with respect to at least one embodiment, the present invention can be further modified within the spirit and scope of this disclosure. This application is therefore intended to cover any variations, uses, or adaptations of the invention using its general principles. Further, this application is intended to cover such departures from the present disclosure as come within known or customary practice in the art to which this invention pertains and which fall within the limits of the appended claims.

What is claimed is:

1. An optical glass having a refractive index n_d of more than 2.10 and comprising at least TiO_2, $NbO_{2.5}$, $LaO_{1.5}$, SiO_2, and B_2O_3, the glass having the following features:

a cation parameter K of $1.8<K\leq 2.8$, wherein $K=(Ti\text{-eq.}+SiO_2+(BO_{1.5})/2)/(La\text{-eq.})$, the molar fractions of Ti-eq., SiO_2, $BO_{1.5}$ and La-eq. in the cation parameter K being in cat %;

a sum total of glass components SiO_2 and B_2O_3 of $8.0 \text{ mol \%}\leq(SiO_2+B_2O_3)\leq 20.0 \text{ mol \%}$, the proportion of B_2O_3 being >0 mol % and the proportion of SiO_2>0 mol %; and

a temperature $T_{max}\leq 1330°$ C.

2. The optical glass of claim **1**, having an internal transmission τ_i of at least 75% measured at a wavelength of 460 nm and a sample thickness of 10 mm.

3. The optical glass of claim **2**, wherein the internal transmission is τ_i at least 90%.

4. The optical glass of claim **1**, having a density of <5.3 g/cm^3 and/or a numerical value for a ratio $(n_d)^2$/density of more than 0.85.

5. The optical glass of claim **1**, wherein the proportion of the components TiO_2 and $LaO_{1.5}$ in the glass is at least 53.0 cat %.

6. The optical glass of claim **5**, wherein the proportion of $NbO_{2.5}$ is at least 7.0 cat %.

7. The optical glass of claim **1**, wherein the proportion of the components TiO_2, $LaO_{1.5}$ and $NbO_{2.5}$ is at least 60.0 cat %.

8. The optical glass of claim **1**, having at least one of the following features:

a proportion of Ti-eq. of at least 43.0 cat % and/or not more than 63.0 cat %;

a proportion of La-eq. of at least 21.0 cat % and/or not more than 35.0 cat %; or

a sum total (Ti-eq.+La-eq.) of at least 72.0 cat % and/or not more than 85.0 cat %.

9. The optical glass of claim **8**, wherein the proportion of La-eq. is not more than 30.0 cat % and/or wherein the proportion of Ti-eq. is at least 45.0 cat %.

10. The optical glass of claim **1**, wherein the cation parameter is at least 1.9.

11. The optical glass of claim **10**, wherein the cation parameter is at least 2.2.

12. The optical glass of claim **1**, comprising the following components in cat %:

SiO_2	>0 to <20.0;
$BO_{1.5}$	>0 to <20.0;
TiO_2	32.0 to 52.0;
$NbO_{2.5}$	3.0 to 15.0;
ZrO_2	0 to 11.0;
WO_3	0 to 5.0;
$TaO_{2.5}$	0 to 5.0;
$AlO_{1.5}$	0 to 5.0;
$SbO_{2.5}$	0 to 0.5;
$AsO_{2.5}$	0 to 0.5;
$LaO_{1.5}$	13.0 to 30.0;
$GdO_{1.5}$	0 to 10.0;
$YO_{1.5}$	0 to 5.0; and
$YbO_{1.5}$	0 to 5.0.

13. The optical glass of claim **1**, comprising the following components in cat %:

SiO_2	>0 to <20.0;
$BO_{1.5}$	>0 to <20.0;
TiO_2	32.0 to 52.0;
$NbO_{2.5}$	4.0 to 15.0;
ZrO_2	0 to 11.0;
WO_3	0 to 5.0;
$TaO_{2.5}$	0 to 5.0;
$AlO_{1.5}$	0 to 5.0;

-continued

$SbO_{2.5}$	0 to 0.5;
$AsO_{2.5}$	0 to 0.5;
$LaO_{1.5}$	13.0 to 28.0;
$GdO_{1.5}$	0 to 10.0;
$YO_{1.5}$	0 to 5.0; and
$YbO_{1.5}$	0 to 5.0.

14. The optical glass of claim **1**, comprising the following components in cat %:

SiO_2	2.0 to 14.0;
$BO_{1.5}$	1.0 to 18.0;
TiO_2	34.0 to 50.0;
$NbO_{2.5}$	5.0 to 13.0;
ZrO_2	2.0 to 8.0;
WO_3	0 to 2.0;
$TaO_{2.5}$	0 to 1.0;
$AlO_{1.5}$	0 to 2.0;
$SbO_{2.5}$	0 to 0.1;
$AsO_{2.5}$	0 to 0.1;
$LaO_{1.5}$	16.0 to 24.0;
$GdO_{1.5}$	2.0 to 8.0;
$YO_{1.5}$	0.3 to 2.0; and
BaO	0 to 6.5.

15. The optical glass of claim **1**, having a content of BaO of not more than 6.5 cat % and/or a content of TiO_2 of at least 39 cat %.

16. The optical glass of claim **1**, having an Abbe number (ν_d) of more than 18.5 and/or less than 30.0.

17. The optical glass of claim **16**, wherein the Abbe number is more than 18.9 and/or less than 25.0.

18. The optical glass of claim **1**, wherein the glass, based on the respective cations, is essentially free of one or more constituents selected from group consisting of bismuth, lead, germanium, phosphate, lithium, magnesium, cadmium, gallium, coloring components, cobalt, vanadium, chromium, molybdenum, copper, nickel, and combinations thereof.

19. A glass article, comprising:

an optical glass having a refractive index n_d of more than 2.10 and comprising at least TiO_2, $NbO_{2.5}$, $LaO_{1.5}$, SiO_2, and B_2O_3, the glass having the following features:

a cation parameter K of $1.8<K\leq 2.8$, wherein K=(Ti-eq.+SiO_2+($BO_{1.5}$)/2)/(La-eq.), the molar fractions of Ti-eq., SiO_2, $BO_{1.5}$ and La-eq. in the cation parameter K being in cat %;

a sum total of glass components SiO_2 and B_2O_3 of 8.0 mol %$\leq(SiO_2+B_2O_3)\leq$20.0 mol %, the proportion of B_2O_3 being >0 mol % and the proportion of SiO_2>0 mol %; and

a temperature $T_{max}\leq$1330° C.;

wherein the glass article is in the form of a glass substrate, a wafer, a lens, a spherical lens, a prism, an asphere, an optical waveguide, a fibre, and/or a plate.

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