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(54) **REINFORCED GLASS PLATE, METHOD FOR MANUFACTURING REINFORCED GLASS PLATE, AND GLASS PLATE TO BE REINFORCED**

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(57) **ABSTRACT**

The present invention provides a tempered glass sheet including as a glass composition, in terms of mol %, 50% to 80% of SiO_2, 7% to 25% of Al_2O_3, 0% to 15% of B_2O_3, 0% to 15% of Li_2O, 0% to 25% of Na_2O, 0% to 10% of K_2O, 0% to 15% of MgO, 0% to 10% of CaO, 0% to 10% of SrO, 0% to 10% of BaO, 0% to 10% of ZnO, 0% to 15% of P_2O_5, 0% to 10% of TiO_2, 0% to 10% of ZrO_2, and 0% to 0.30% of SnO_2, having a value of $[B_2O_3]+[MgO]+[CaO]$ of from 0.1% to 30%, and having a value of $([Li_2O]+[Na_2O]+[K_2O])/[Al_2O_3]$ of from 0.5 to 2.0.

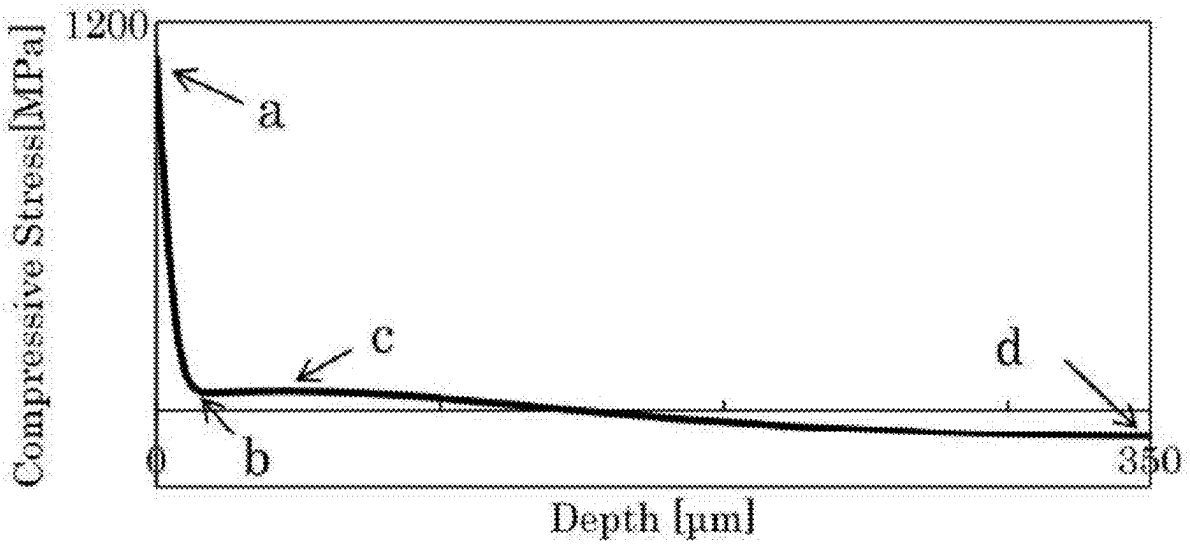
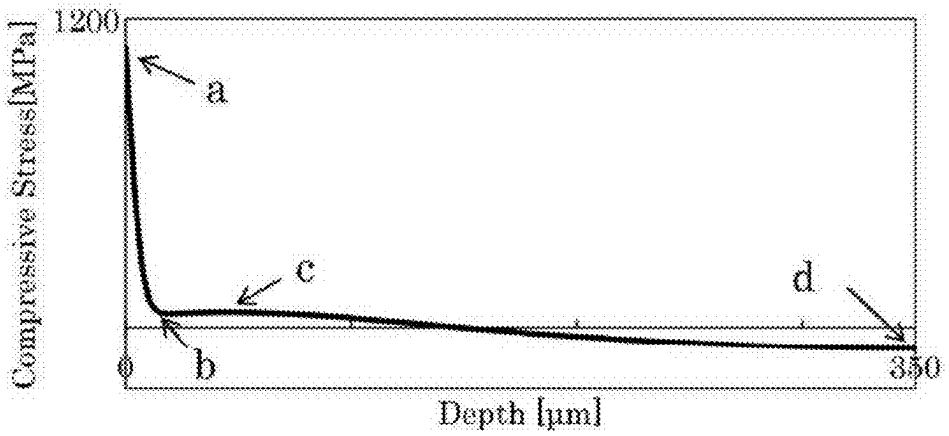


Fig. 1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a
c
d
b
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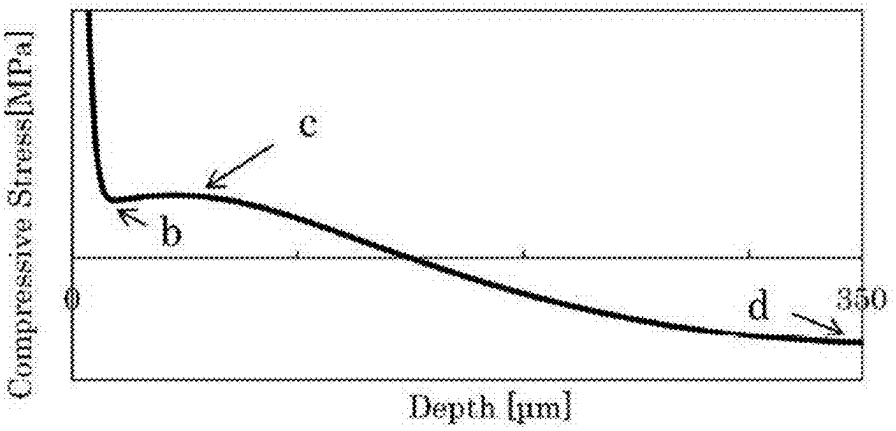
350
Depth [μm]

Fig. 2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b
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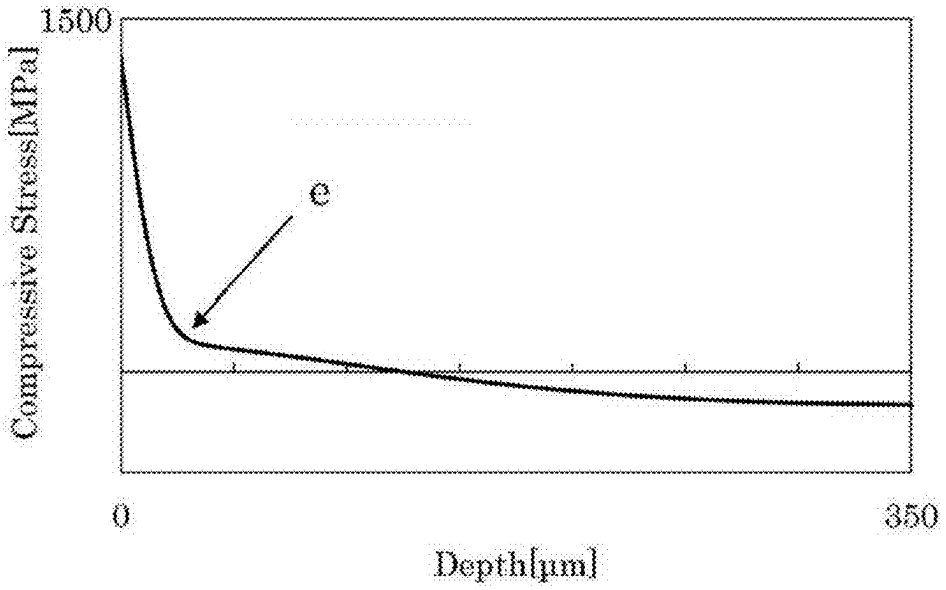
Depth [μm]

Fig. 3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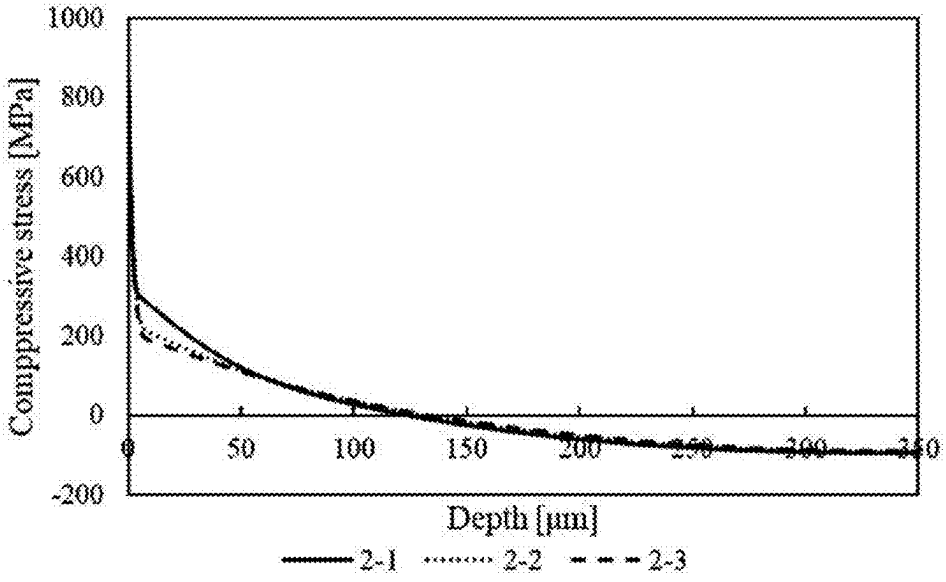
Depth[μm]

Fig. 4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Compressive stress [MPa]
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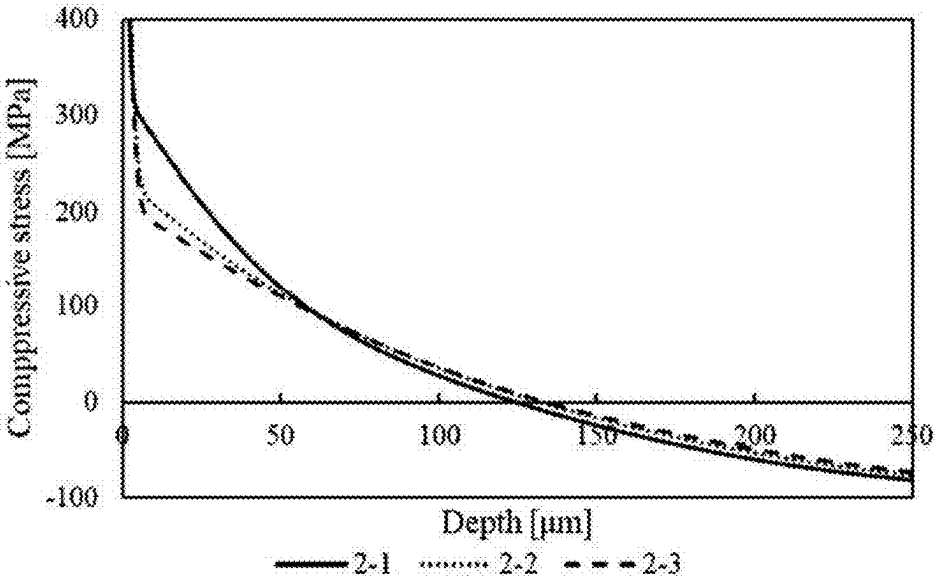
100
150
200
250
300
350
Depth [μm]
2-1
2-2
2-3

Fig. 5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100
150
200
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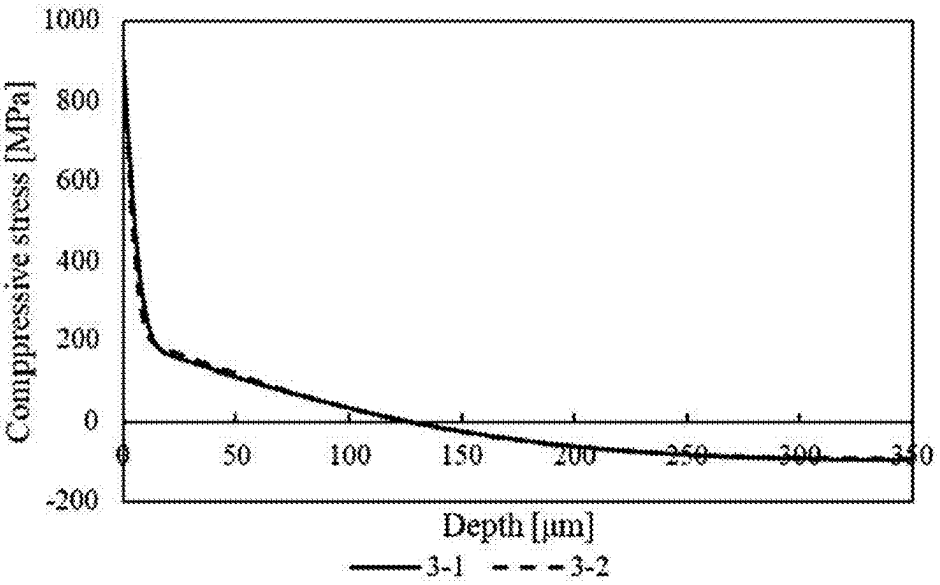
Depth [μm]
2-1
2-2
2-3

Fig. 6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400
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-200
Compressive stress [MPa]
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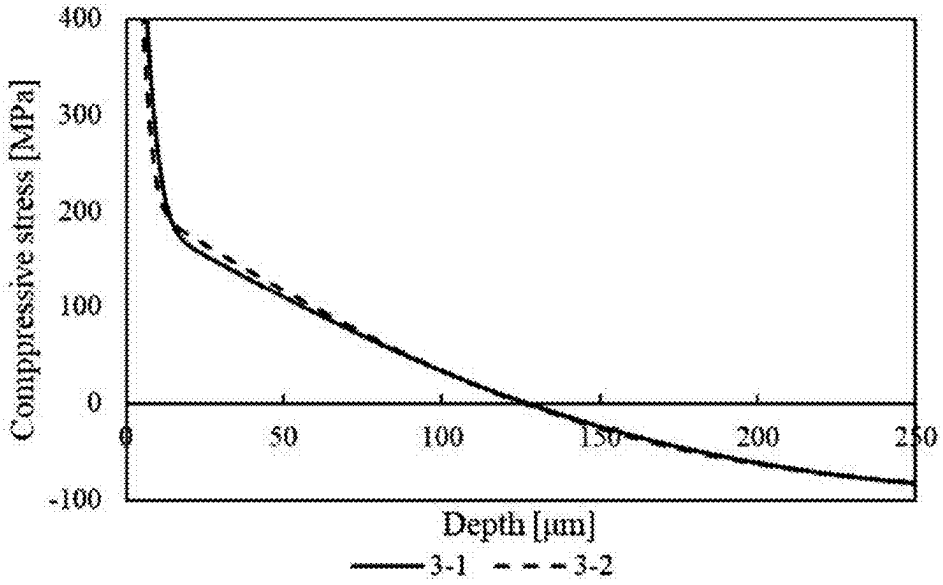
50
100
150
200
250
300
350
Depth [μm]
3-1
3-2

Fig. 7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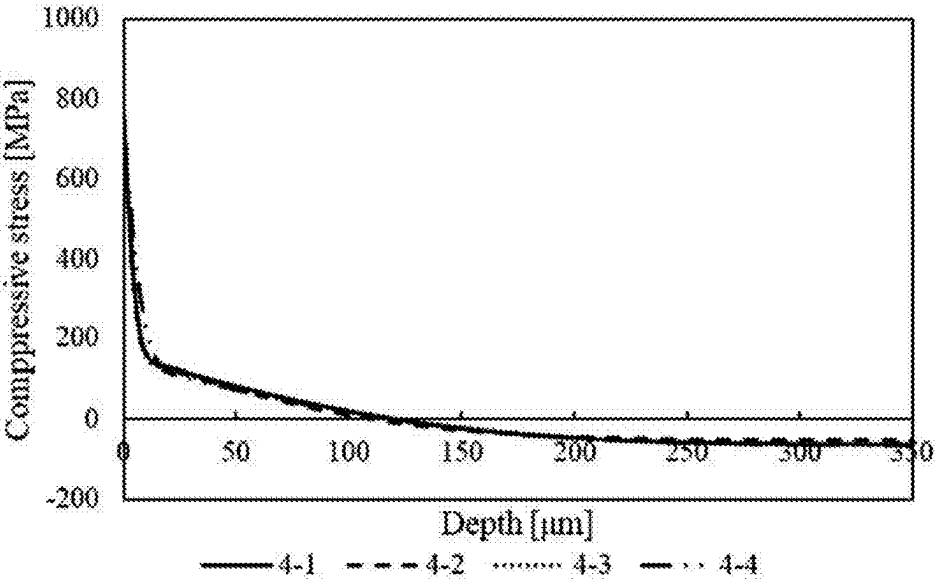
-100
Compressive stress [MPa]
0
50
100
150
200
250
Depth [μm]
3-1
3-2

Fig. 8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600
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-200
Compressive stress [MPa]
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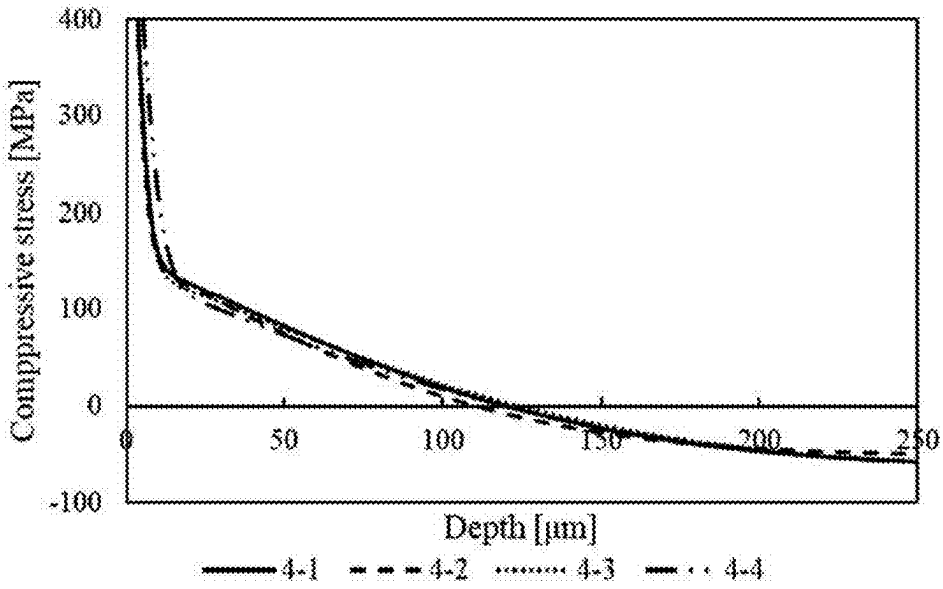
100
150
200
250
300
350
Depth [μm]
4-1
4-2
4-3
4-4

Fig. 9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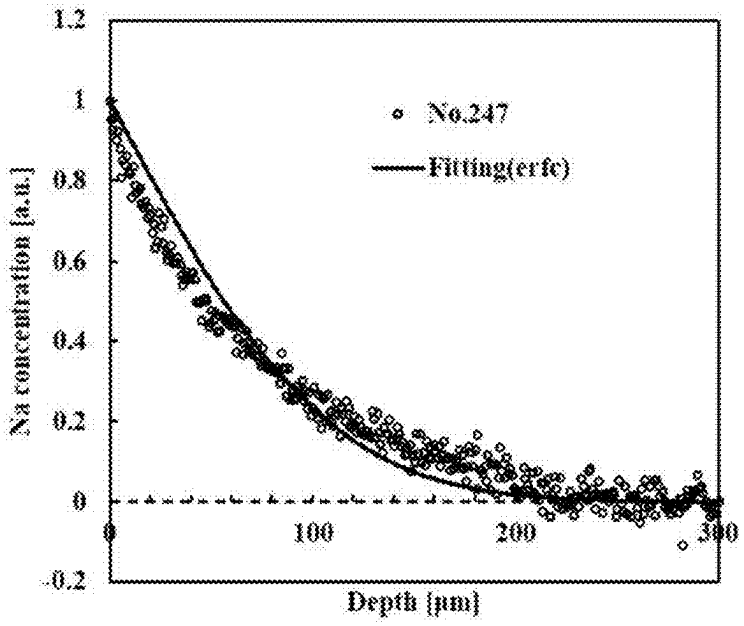
300
200
100
0
-100
Compressive stress [MPa]
0
50
100
150
200
250
Depth [μm]
4-1
4-2
4-3
4-4

Fig. 10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1
0.8
0.6
0.4
0.2
0
-0.2
Na concentration [a.u.]
No.247
Fitting(erfc)
0
100
200
300
Depth [μm]

REINFORCED GLASS PLATE, METHOD FOR MANUFACTURING REINFORCED GLASS PLATE, AND GLASS PLATE TO BE REINFORCED

TECHNICAL FIELD

[0001] The present invention relates to a tempered glass sheet and a method of manufacturing the same, and more particularly, to a tempered glass sheet suitable as a cover glass for a touch panel display of a cellular phone, a digital camera, a personal digital assistant (PDA), or the like, a method of manufacturing a tempered glass sheet, and a glass sheet to be tempered.

BACKGROUND ART

[0002] In applications, such as a cellular phone (in particular, a smartphone), a digital camera, and a personal digital assistant (PDA), a tempered glass sheet obtained through ion exchange treatment is used as a cover glass for a touch panel display (see Patent Literature 1).

[0003] Incidentally, when a smartphone is dropped onto a road surface or the like by mistake, the smartphone becomes unusable in some cases owing to breakage of a cover glass. Accordingly, in order to avoid such situation, it is important to increase the strength of the tempered glass sheet.

[0004] An effective method of increasing the strength of the tempered glass sheet is to increase a depth of compression. Specifically, when the cover glass collides with the road surface at the time of dropping of the smartphone, protrusions or sand grains on the road surface penetrate into the cover glass to reach a tensile stress layer, which leads to the breakage of the cover glass. In view of the foregoing, when the depth of compression of a compressive stress layer is increased, the protrusions or the sand grains on the road surface are less liable to reach the tensile stress layer, and thus the breakage probability of the cover glass can be reduced (see Patent Literature 2).

CITATION LIST

[0005] Patent Literature 1: JP 2006-83045 A

[0006] Patent Literature 2: JP 2017-527513 A

SUMMARY OF INVENTION

Technical Problem

[0007] According to investigations made by the inventors of the present invention, it is conceived that an increase in compressive stress value at a depth corresponding to the size of an intrusion such as sand grains responsible for the breakage (e.g., at a depth of 30 μm from the outermost surface) is effective in further increasing the strength of the tempered glass sheet. With the above-mentioned configuration, fracture of the tempered glass sheet from an inside thereof caused by the intrusion is easily suppressed. However, with the related-art glass (glass composition), even when ion exchange conditions are changed in order to increase the compressive stress value at the predetermined depth, it has been difficult to increase the compressive stress value at the predetermined depth. In addition, when the compressive stress value at the predetermined depth is increased, it has been difficult to concurrently achieve a high surface compressive stress or a large depth of compression.

[0008] The present invention has been made in view of the above-mentioned circumstances, and a technical object of the present invention is to provide a tempered glass sheet, which is less liable to be broken than related-art alkali aluminosilicate glass, and a method of manufacturing the same.

Solution to Problem

[0009] (Invention 1) According to one embodiment of the present invention, there is provided a tempered glass sheet having a compressive stress layer in a surface thereof, the tempered glass sheet comprising as a glass composition, in terms of mol %, 50% to 80% of SiO_2, 7% to 25% of Al_2O_3, 0% to 15% of B_2O_3, 0% to 15% of Li_2O, 0% to 25% of Na_2O, 0% to 10% of K_2O, 0% to 15% of MgO, 0% to 10% of CaO, 0% to 10% of SrO, 0% to 10% of BaO, 0% to 10% of ZnO, 0% to 15% of P_2O_5, 0% to 10% of TiO_2, 0% to 10% of ZrO_2, and 0% to 0.30% of SnO_2, having a value of $[B_2O_3]+[MgO]+[CaO]$ of from 0.1% to 30%, and having a value of $([Li_2O]+[Na_2O]+[K_2O])/[Al_2O_3]$ of from 0.5 to 2.0. Herein, the "$[B_2O_3]$" refers to the content of B_2O_3 in terms of mol %. The "[MgO]" refers to the content of MgO in terms of mol %. The "[CaO]" refers to the content of CaO in terms of mol %. The "$[Li_2O]$" refers to the content of Li_2O in terms of mol %. The "$[Na_2O]$" refers to the content of Na_2O in terms of mol %. The "$[K_2O]$" refers to the content of K_2O in terms of mol %. The "$[Al_2O_3]$" refers to the content of Al_2O_3 in terms of mol %. The "$[B_2O_3]+[MgO]+[CaO]$" refers to the total content of B_2O_3, MgO, and CaO. The "$([Li_2O]+[Na_2O]+[K_2O])/[Al_2O_3]$" refers to a value obtained by dividing the total content of Li_2O, Na_2O, and K_2O by the content of Al_2O_3.

[0010] (Invention 1-2) In addition, it is preferred that the tempered glass sheet according to the one embodiment of the present invention have a Z value calculated by the following equation of 18.0 or more.

$$Z = 0.13 \times [SiO_2] + 2.36 \times [Al_2O_3] - 0.14 \times [B_2O_3] + 4.90 \times [Li_2O] - 5.53 \times [Na_2O] - 2.14 \times [MgO] - 2.34 \times [CaO]$$

[0011] Herein, the "$[SiO_2]$" refers to the content of SiO_2 in terms of mol %.

[0012] With the above-mentioned configuration, the efficiency of ion exchange between a Li ion in glass and a Na ion in a molten salt, and the efficiency of ion exchange between a Na ion in the glass and a K ion in the molten salt can be balanced.

[0013] (Invention 1-3) In addition, it is preferred that the tempered glass sheet according to the one embodiment of the present invention have a Z value calculated by the following equation of 20.0 or more.

$$Z = 0.13 \times [SiO_2] + 2.36 \times [Al_2O_3] - 0.14 \times [B_2O_3] + 4.90 \times [Li_2O] - 5.53 \times [Na_2O] - 2.14 \times [MgO] - 2.34 \times [CaO]$$

[0014] (Invention 1-4) In addition, it is preferred that the tempered glass sheet according to the one embodiment of the present invention have a molar ratio $[Na_2O]/[Li_2O]$ of 1.0 or less.

[0015] With the above-mentioned configuration, the efficiency of ion exchange between a Li ion in the glass and a Na ion in the molten salt can be improved.

[0016] (Invention 1-5) In addition, it is preferred that the tempered glass sheet according to the one embodiment of the present invention have a Y value calculated by the following equation of 5.0 or more.

$$Y = 3 + 0.21 \times [SiO_2] + 0.25 \times [Al_2O_3] - 0.33 \times [B_2O_3] - 0.55 \times [Li_2O] + 0.45 \times [Na_2O] - 0.97 \times [MgO] - 1.46 \times [CaO]$$

[0017] Herein, the "$[SiO_2]$" refers to the content of SiO_2 in terms of mol %.

[0018] With the above-mentioned configuration, the efficiency of ion exchange between a Na ion in the glass and a K ion in the molten salt can be improved.

[0019] (Invention 1-6) In addition, it is preferred that the tempered glass sheet according to the one embodiment of the present invention have a Y value calculated by the following equation of from 6.0 to 30.

$$Y = 3 + 0.21 \times [SiO_2] + 0.25 \times [Al_2O_3] - 0.33 \times [B_2O_3] - 0.55 \times [Li_2O] + 0.45 \times [Na_2O] - 0.97 \times [MgO] - 1.46 \times [CaO]$$

[0020] With the above-mentioned configuration, the efficiency of ion exchange between a Na ion in the glass and a K ion in the molten salt can be further improved.

[0021] (Invention 1-7) In addition, it is preferred that the tempered glass sheet according to the one embodiment of the present invention have an X value calculated by the following equation of 300 or more.

$$X = -1.49 \times [SiO_2] + 26.98 \times [Al_2O_3] - 3.23 \times [B_2O_3] + 48.56 \times [Li_2O] - 24.31 \times [Na_2O] - 0.28 \times [MgO] + 2.74 \times [CaO]$$

[0022] With the above-mentioned configuration, the efficiency of ion exchange between a Li ion in the glass and a Na ion in the molten salt can be improved.

[0023] (Invention 1-8) In addition, it is preferred that the tempered glass sheet according to the one embodiment of the present invention have a W value calculated by the following equation of 340 or more.

$$W = 0.07 \times [SiO_2] + 18.17 \times [Al_2O_3] - 4.42 \times [B_2O_3] + 41.43 \times [Li_2O] - 29.30 \times [Na_2O] + 1.43 \times [MgO] - 10.43 \times [CaO]$$

[0024] With the above-mentioned configuration, the Young's modulus of the tempered glass sheet can be increased.

[0025] (Invention 1-9) In addition, it is preferred that the tempered glass sheet according to the one embodiment of the present invention have a value of $[Al_2O_3]+[Li_2O]+[Na_2O]+[K_2O]$ of 10.5% or more.

[0026] With the above-mentioned configuration, the ion exchange performance of the tempered glass sheet can be improved.

[0027] (Invention 1-10) In addition, it is preferred that the tempered glass sheet according to the one embodiment of the present invention have a molar ratio $[Li_2O]/[Al_2O_3]$ of 0.1 or more.

[0028] With the above-mentioned configuration, the ion exchange performance of the tempered glass sheet can be further improved.

[0029] (Invention 1-11) In addition, it is preferred that the tempered glass sheet according to the one embodiment of the present invention have a U value calculated by the following equation of 700 or more.

$$U = 87.39 \times [SiO_2] + 180.12 \times [Al_2O_3] + 93.63 \times [B_2O_3] + 113.78 \times ([MgO] + [CaO] + [BaO] + [SrO]) - 46.2 \times [Li_2O] - 71.1 \times [Na_2O] - 58.6 \times [K_2O] - 40.0 \times [P_2O_5]$$

[0030] With the above-mentioned configuration, the fracture toughness Kc of the tempered glass sheet can be increased.

[0031] (Invention 1-12) In addition, it is preferred that the tempered glass sheet according to the one embodiment of the present invention have a Q value calculated by the following equation of −30% or more.

$$Q = [SiO_2] + 1.2 \times [P_2O_5] - 3 \times [Al_2O_3] - [B_2O_3] - 2 \times [Li_2O] - 1.5 \times [Na_2O] - [K_2O]$$

[0032] With the above-mentioned configuration, the acid resistance of the tempered glass sheet can be increased.

[0033] (Invention 1-13) In addition, it is preferred that the tempered glass sheet according to the one embodiment of the present invention comprise Cl as the glass composition and have a content of Cl of 0.02 mol % or more.

[0034] With the above-mentioned configuration, a bubble diameter in molten glass is easily expanded, and a high fining effect is obtained.

[0035] (Invention 1-14) In addition, it is preferred that the tempered glass sheet according to the one embodiment of the present invention comprise MoO_3 as the glass composition and have a content of MoO_3 of 0.0001 mol % or more.

[0036] With the above-mentioned configuration, the tempered glass sheet easily absorbs UV light, and deterioration of an element in a device caused by UV light can be suppressed.

[0037] (Invention 1-15) In addition, it is preferred that the tempered glass sheet according to the one embodiment of the present invention have a softening point (Ts) of 920° C. or less. Herein, the "softening point" refers to a value measured based on a method of ASTM C338.

[0038] With the above-mentioned configuration, the manufacturing cost of the tempered glass sheet at the time of bending processing is easily reduced.

[0039] (Invention 1-16) In addition, it is preferred that the tempered glass sheet according to the one embodiment of the present invention have a compressive stress value CS of the compressive stress layer on an outermost surface of from

200 MPa to 1,200 MPa, and a depth of compression DOC of the compressive stress layer of from 3 μm to 200 μm. Herein, the terms "compressive stress value on an outermost surface" and "depth of compression" each refer to, for example, a value measured with FSM-6000 (manufactured by Orihara Industrial Co., Ltd.) in the case where the compressive stress is attributed to a potassium ion introduced through ion exchange, or a value measured from a retardation distribution curve observed with a scattered light photoelastic stress meter SLP-2000 (manufactured by Orihara Industrial Co., Ltd.) in the case where the compressive stress is attributed to a Na ion introduced through ion exchange. Moreover, the term "depth of compression" refers to a depth at which the stress value becomes zero. In calculation of the stress characteristics of each sample, a refractive index and a photoelastic constant were used. A value measured by a V-block method was used as the refractive index. A value measured by optical heterodyne interferometry was used as the photoelastic constant.

[0040] With the above-mentioned configuration, a tempered glass sheet having high strength is obtained.

[0041] (Invention 1-17) In addition, it is preferred that the tempered glass sheet according to the one embodiment of the present invention have a depth of compression DOC of the compressive stress layer of from 50 μm to 200 μm, and a compressive stress value CS30 of the compressive stress layer at a depth of 30 μm from an outermost surface of from 35 MPa to 400 MPa.

[0042] With the above-mentioned configuration, a tempered glass sheet that is less liable to be broken at the time of dropping is obtained.

[0043] (Invention 1-18) In addition, in the tempered glass sheet according to the one embodiment of the present invention, it is preferred that a compressive stress value CS30 of the compressive stress layer at a depth of 30 μm from the surface be 120 MPa or more, and a compressive stress value CS of the compressive stress layer on the outermost surface be 400 MPa or more.

[0044] With the above-mentioned configuration, a higher internal stress is obtained, and the drop strength of a cover glass for a smartphone can be increased.

[0045] (Invention 1-19) In addition, it is preferred that the tempered glass sheet according to the one embodiment of the present invention have a temperature at a viscosity at high temperature of $10^{2.5}$ dPa·s of 1,680° C. or less. Herein, the "temperature at a viscosity at high temperature of $10^{2.5}$ dPa·s" may be measured, for example, by a platinum sphere pull up method.

[0046] With the above-mentioned configuration, the molten glass is easily formed into a sheet shape.

[0047] (Invention 1-20) In addition, it is preferred that the tempered glass sheet according to the one embodiment of the present invention have an overflow-merged surface in a middle portion thereof in a thickness direction. Herein, the "overflow down-draw method" is a method involving causing molten glass to overflow from both sides of forming body refractory, and subjecting the overflowing molten glasses to down-draw downward while the molten glasses are merged at the lower end of the forming body refractory, to thereby manufacture a glass sheet.

[0048] With the above-mentioned configuration, a tempered surface glass sheet having satisfactory quality can be inexpensively manufactured without polishing.

[0049] (Invention 1-21) In addition, it is preferred that a stress profile of the tempered glass sheet according to the one embodiment of the present invention in a thickness direction have an inflection point.

[0050] With the above-mentioned configuration, a tempered glass sheet having a high compressive stress on the surface and having a large depth of compression is obtained.

[0051] (Invention 1-22) In addition, it is preferred that the tempered glass sheet according to the one embodiment of the present invention have a Na ion (substantially, Na ion-Li ion) mutual diffusion coefficient D_{Na} at 380° C. in a deep region of from 1×10^{-14} m^2 sec^{-1} to 1×10^{-11} m^2 sec^{-1} and have a K ion (substantially, K ion-Na ion) mutual diffusion coefficient D_K at the same temperature in a shallow region of from 1×10^{-17} m^2 sec^{-1} to 1×10^{-14} m^2 sec^{-1}, and besides, have a ratio D_K/D_{Na} therebetween of 0.0001 or more.

[0052] (Invention 1-23) In addition, it is preferred that the tempered glass sheet according to the one embodiment of the present invention have a Na ion mutual diffusion coefficient D_{Na} of from 1×10^{-14} m^2 sec^{-1} to 1×10^{-11} m^2 sec^{-1} when subjected to ion exchange with $NaNO_3$ at 380° C. and have a K ion mutual diffusion coefficient D_K of from 1×10^{-17} m^2 sec^{-1} to 1×10^{-14} m^2 sec^{-1} when subjected to ion exchange with KNO_3 at 380° C., and besides, have a ratio D_K/D_{Na} therebetween of 0.0001 or more.

[0053] (Invention 2) According to one embodiment of the present invention, there is provided a tempered glass sheet, comprising as a glass composition, in terms of mol %, 50% to 80% of SiO_2, 7% to 25% of Al_2O_3, 1% to 15% of B_2O_3, 0% to 15% of Li_2O, 0% to 25% of Na_2O, 0% to 10% of K_2O, 0% to 15% of MgO, 0% to 10% of CaO, 0% to 10% of BaO, 0% to 10% of SrO, 0% to 10% of ZnO, 0% to 4% of P_2O_5, 0.001% to 0.1% of TiO_2, 0% to 10% of ZrO_2, 0.001% to 0.1% of Fe_2O_3, and 0.001% to 0.30% of SnO_2, having a value of $[B_2O_3]+[MgO]+[CaO]$ of from 0.1% to 30%, and having a value of $([Li_2O]+[Na_2O]+[K_2O])/[Al_2O_3]$ of from 0.5 to 2.0.

[0054] (Invention 3) In addition, according to one embodiment of the present invention, there is provided a method of manufacturing a tempered glass sheet, comprising: a preparation step of preparing a glass sheet to be tempered including as a glass composition, in terms of mol %, 50% to 80% of SiO_2, 7% to 25% of Al_2O_3, 0% to 15% of B_2O_3, 0% to 15% of Li_2O, 0% to 25% of Na_2O, 0% to 10% of K_2O, 0% to 15% of MgO, 0% to 10% of CaO, 0% to 10% of BaO, 0% to 10% of SrO, 0% to 10% of ZnO, 0% to 15% of P_2O_5, 0% to 10% of TiO_2, 0% to 10% of ZrO_2, and 0% to 0.30% of SnO_2, having a value of $[B_2O_3]+[MgO]+[CaO]$ of from 0.1% to 30%, and having a value of $([Li_2O]+[Na_2O]+[K_2O])/[Al_2O_3]$ of from 0.5 to 2.0; and an ion exchange step of subjecting the glass sheet to be tempered to ion exchange treatment a plurality of times to provide a tempered glass sheet having a compressive stress layer in a surface thereof.

[0055] (Invention 4) In addition, according to one embodiment of the present invention, there is provided a glass sheet to be tempered, comprising as a glass composition, in terms of mol %, 50% to 80% of SiO_2, 7% to 25% of Al_2O_3, 0% to 15% of B_2O_3, 0% to 15% of Li_2O, 0% to 25% of Na_2O, 0% to 10% of K_2O, 0% to 15% of MgO, 0% to 10% of CaO, 0% to 10% of BaO, 0% to 10% of SrO, 0% to 10% of ZnO, 0% to 15% of P_2O_5, 0% to 10% of TiO_2, 0% to 10% of ZrO_2, and 0% to 0.30% of SnO_2, having a value of $[B_2O_3]+[MgO]+[CaO]$ of from 0.1% to 30%, and having a value of $([Li_2O]+[Na_2O]+[K_2O])/[Al_2O_3]$ of from 0.5 to 2.0.

[0056] (Invention 4-1) In addition, it is preferred that the glass sheet to be tempered according to the one embodiment of the present invention have a Na ion mutual diffusion coefficient D_{Na} Of from 1×10^{-14} m^2 sec^{-1} to 1×10^{-11} m^2 sec^{-1} when subjected to ion exchange with $NaNO_3$ at 380° C. and have a K ion mutual diffusion coefficient D_K of from 1×10^{-17} m^2 sec^{-1} to 1×10^{-14} m^2 sec^{-1} when subjected to ion exchange with KNO_3 at 380° C., and besides, have a ratio D_K/D_{Na} therebetween of 0.001 or more.

[0057] With the above-mentioned configuration, when a compressive stress value at a predetermined depth (e.g., at a depth of 30 μm from the outermost surface) is increased, a high surface compressive stress or a large depth of compression can be concurrently achieved.

[0058] (Invention 4-2) In addition, it is preferred that the glass sheet to be tempered according to the one embodiment of the present invention have a Z value calculated by the following equation of 18.0 or more.

$$Z = 0.13\times[SiO_2] + 2.36\times[Al_2O_3] - 0.14\times[B_2O_3] + 4.90\times[Li_2O] - 5.53\times[Na_2O] - 2.14\times[MgO] - 2.34\times[CaO]$$

[0059] (Invention 4-3) In addition, it is preferred that the glass sheet to be tempered according to the one embodiment of the present invention have a Z value calculated by the following equation of 20.0 or more.

$$Z = 0.13\times[SiO_2] + 2.36\times[Al_2O_3] - 0.14\times[B_2O_3] + 4.90\times[Li_2O] - 5.53\times[Na_2O] - 2.14\times[MgO] - 2.34\times[CaO]$$

[0060] (Invention 4-4) In addition, it is preferred that the glass sheet to be tempered according to the one embodiment of the present invention have a molar ratio $[Na_2O]/[Li_2O]$ of 1.0 or less.

[0061] (Invention 4-5) In addition, it is preferred that the glass sheet to be tempered according to the one embodiment of the present invention have a Y value calculated by the following equation of 5.0 or more.

$$Y = 3 + 0.21\times[SiO_2] + 0.25\times[Al_2O_3] - 0.33\times[B_2O_3] - 0.55\times[Li_2O] + 0.45\times[Na_2O] - 0.97\times[MgO] - 1.46\times[CaO]$$

[0062] (Invention 4-6) In addition, it is preferred that the glass sheet to be tempered according to the one embodiment of the present invention have a Y value calculated by the following equation of from 6.0 to 30.

$$Y = 3 + 0.21\times[SiO_2] + 0.25\times[Al_2O_3] - 0.33\times[B_2O_3] - 0.55\times[Li_2O] + 0.45\times[Na_2O] - 0.97\times[MgO] - 1.46\times[CaO]$$

[0063] (Invention 4-7) In addition, it is preferred that the glass sheet to be tempered according to the one embodiment of the present invention have an X value calculated by the following equation of 300 or more.

$$X = -1.49\times[SiO_2] + 26.98\times[Al_2O_3] - 3.23\times[B_2O_3] + 48.56\times[Li_2O] - 24.31\times[Na_2O] - 0.28\times[MgO] + 2.74\times[CaO]$$

[0064] (Invention 4-8) In addition, it is preferred that the glass sheet to be tempered according to the one embodiment of the present invention have a W value calculated by the following equation of 340 or more.

$$W = 0.07\times[SiO_2] + 18.17\times[Al_2O_3] - 4.42\times[B_2O_3] + 41.43\times[Li_2O] - 29.30\times[Na_2O] + 1.43\times[MgO] - 10.43\times[CaO]$$

[0065] (Invention 4-9) In addition, it is preferred that the glass sheet to be tempered according to the one embodiment of the present invention have a value of $[Al_2O_3]+[Li_2O]+[Na_2O]+[K_2O]$ of 10.5% or more.

[0066] (Invention 4-10) In addition, it is preferred that the glass sheet to be tempered according to the one embodiment of the present invention have a molar ratio $[Li_2O]/[Al_2O_3]$ of 0.1 or more.

[0067] (Invention 4-11) In addition, it is preferred that the glass sheet to be tempered according to the one embodiment of the present invention have a U value calculated by the following equation of 7,000 or more.

$$U = 87.39\times[SiO_2] + 180.12\times[Al_2O_3] + 93.63\times[B_2O_3] + 113.78\times([MgO] + [CaO]+[BaO]+[SrO]) - 46.2\times[Li_2O] - 71.1\times[Na_2O] - 58.6\times[K_2O] - 40.0\times[P_2O_5]$$

[0068] (Invention 4-12) In addition, it is preferred that the glass sheet to be tempered according to the one embodiment of the present invention have a Q value calculated by the following equation of −30% or more.

$$Q = [SiO_2] + 1.2\times[P_2O_5] - 3\times[Al_2O_3] - [B_2O_3] - 2\times[Li_2O] - 1.5\times[Na_2O] - [K_2O]$$

[0069] (Invention 4-13) In addition, it is preferred that the glass sheet to be tempered according to the one embodiment of the present invention comprise Cl as the glass composition and have a content of Cl of 0.02 mol % or more.

[0070] (Invention 4-14) In addition, it is preferred that the glass sheet to be tempered according to the one embodiment of the present invention comprise MoO_3 as the glass composition and have a content of MoO_3 of 0.0001 mol % or more.

[0071] (Invention 4-15) In addition, it is preferred that the glass sheet to be tempered according to the one embodiment of the present invention have a softening point (Ts) of 920° C. or less. Herein, the "softening point" refers to a value measured based on a method of ASTM C338.

[0072] (Invention 5) In addition, according to one embodiment of the present invention, there is provided a method of manufacturing a tempered glass sheet, comprising a preparation step of preparing a glass sheet to be tempered having

a Na ion mutual diffusion coefficient D_{Na} Of from 1×10^{-14} m^2 sec^{-1} to 1×10^{-11} m^2 sec^{-1} when subjected to ion exchange with $NaNO_3$ at 380° C. and having a K ion mutual diffusion coefficient D_K of from 1×10^{-17} m^2 sec^{-1} to 1×10^{-14} m^2 sec^{-1} when subjected to ion exchange with KNO_3 at 380° C., and besides, having a ratio D_K/D_{Na} therebetween of 0.001 or more; an ion exchange step of subjecting the glass sheet to be tempered to ion exchange treatment a plurality of times to provide a tempered glass sheet having a compressive stress layer in a surface thereof.

Advantageous Effects of Invention

[0073] According to the present invention, the tempered glass sheet, which is less liable to be broken at the time of dropping than related-art alkali aluminosilicate glass, and the method of manufacturing the same can be provided.

BRIEF DESCRIPTION OF DRAWINGS

[0074] FIG. **1** is an explanatory view for illustrating an example of a stress profile having a first peak "a", a first bottom "b", a second peak "c", and a second bottom "d".

[0075] FIG. **2** is an explanatory view for illustrating a low compressive stress region in the stress profile of FIG. **1** in an enlarged manner.

[0076] FIG. **3** is an explanatory view for illustrating an example of a stress profile having an inflection point "e".

[0077] FIG. **4** is a graph showing stress profiles of Examples 2-1 to 2-3.

[0078] FIG. **5** is a graph showing low compressive stress regions in the stress profiles of Examples 2-1 to 2-3 of FIG. **4** in an enlarged manner.

[0079] FIG. **6** is a graph showing stress profiles of Examples 3-1 and 3-2.

[0080] FIG. **7** is a graph showing low compressive stress regions in the stress profiles of Examples 3-1 and 3-2 of FIG. **6** in an enlarged manner.

[0081] FIG. **8** is a graph showing stress profiles of Examples 4-1 to 4-4.

[0082] FIG. **9** is a graph showing low compressive stress regions in the stress profiles of Examples 4-1 to 4-4 of FIG. **8** in an enlarged manner.

[0083] FIG. **10** is an explanatory view for illustrating an example of a Na ion concentration profile measured with an EPMA.

DESCRIPTION OF EMBODIMENTS

[0084] In the present invention, the term "tempered glass sheet" refers to a glass sheet having been subjected to ion exchange treatment and having a compressive stress layer in a surface thereof. The term "glass sheet to be tempered" refers to a glass sheet not having been subjected to the ion exchange treatment (before the ion exchange treatment).

[0085] A tempered glass sheet (glass sheet to be tempered) of the present invention comprises as a glass composition, in terms of mol %, 50% to 80% of SiO_2, 7% to 25% of Al_2O_3, 0% to 15% of B_2O_3, 0% to 15% of Li_2O, 0% to 25% of Na_2O, 0% to 10% of K_2O, 0% to 15% of MgO, 0% to 10% of CaO, 0% to 10% of BaO, 0% to 10% of SrO, 0% to 10% of ZnO, 0% to 15% of P_2O_5, 0% to 10% of TiO_2, 0% to 10% of ZrO_2, and 0% to 0.30% of SnO_2, has a value of $[B_2O_3]+[MgO]+[CaO]$ of from 0.1% to 30%, and has a value of $([Li_2O]+[Na_2O]+[K_2O])/[Al_2O_3]$ of from 0.5 to 2.0. Reasons why the content ranges of the components are restricted are described below. In the description of the content range of each component, the expression "%" means "mol %" unless otherwise specified.

[0086] SiO_2 is a component that forms a glass network. When the content of SiO_2 is too small, vitrification does not occur easily, and a thermal expansion coefficient becomes too high, with the result that thermal shock resistance is liable to be reduced. Accordingly, a suitable lower limit range of the content of SiO_2 is 50% or more, 52% or more, 55% or more, 57% or more, 58% or more, 58.5% or more, 59% or more, 60% or more, 61% or more, 62% or more, 62.5% or more, or 63% or more, particularly 63.5% or more. Meanwhile, when the content of SiO_2 is too large, meltability and formability are liable to be reduced, and the thermal expansion coefficient is excessively reduced, with the result that it becomes difficult to match the thermal expansion coefficient with those of peripheral materials. Accordingly, a suitable upper limit range of the content of SiO_2 is 80% or less, 75% or less, 73% or less, 72% or less, 71% or less, 70.5% or less, 70% or less, 69.5% or less, 69% or less, 68.5% or less, 68% or less, 67.8% or less, 67.5% or less, or 67.2% or less, particularly 67% or less.

[0087] Al_2O_3 is a component improves ion exchange performance, and is also a component that increases a strain point, a Young's modulus, fracture toughness, and a Vickers hardness. Accordingly, a suitable lower limit range of the content of Al_2O_3 is 7% or more, 7.2% or more, 7.5% or more, 7.8% or more, 8% or more, 8.2% or more, 8.5% or more, 9% or more, 9.2% or more, 9.4% or more, 9.5% or more, 9.8% or more, 10.0% or more, 10.3% or more, 10.5% or more, 10.8% or more, 11% or more, 11.2% or more, 11.4% or more, or 11.6% or more, particularly 11.8% or more. Meanwhile, when the content of Al_2O_3 is too large, a viscosity at high temperature is increased, with the result that the meltability and the formability are liable to be reduced. In addition, a devitrified crystal is liable to be precipitated in glass, and it becomes difficult to form the glass into a sheet shape by an overflow down-draw method or the like. Particularly when the glass is formed into a sheet shape by an overflow down-draw method involving using alumina-based refractory as forming body refractory, a devitrified crystal of spinel is liable to be precipitated at an interface with the alumina-based refractory. Further, acid resistance is reduced, with the result that it becomes difficult to subject the glass to an acid treatment step. Accordingly, a suitable upper limit range of the content of Al_2O_3 is 25% or less, 23% or less, 21% or less, 20.5% or less, 20% or less, 19.8% or less, 19.5% or less, 19.0% or less, 18.5% or less, 18% or less, 17.5% or less, 17% or less, 16.5% or less, 15.5% or less, 15.2% or less, 15% or less, 14.9% or less, 14.7% or less, 14.5% or less, 14.3% or less, 14% or less, or 13.5% or less, particularly 13% or less. When the content of Al_2O_3, which has a large influence on the ion exchange performance, is set to fall within the suitable ranges, it becomes easy to form a profile having a first peak "a", a first bottom "b", a second peak "c", and a second bottom "d".

[0088] B_2O_3 is a component that reduces the viscosity at high temperature and a density, and stabilizes the glass to cause less precipitation of a crystal, to thereby reduce a liquidus temperature. In addition, B_2O_3 is a component that increases fracture toughness K1c and fracture energy γ. Further, B_2O_3 is a component that increases oxygen electron constraint force exhibited by a cation to reduce the basicity of the glass. When the content of B_2O_3 is too small, a depth

of compression (DOC_{Na}) obtained through ion exchange between a Li ion in the glass and a Na ion in a molten salt is excessively increased, with the result that a compressive stress value at a predetermined depth (from 5 μm to 50 μm) from the outermost surface is liable to be reduced. In addition, the glass may become unstable, and devitrification resistance may be reduced. In addition, the basicity of the glass is excessively increased, and the release amount of O_2 through a reaction of a fining agent is reduced to reduce a bubble forming property, with the result that bubbles may remain in the glass when the glass is formed into a sheet shape. Accordingly, a suitable lower limit range of the content of B_2O_3 is 0% or more, 0.10% or more, 0.15% or more, 0.20% or more, 0.30% or more, 0.4% or more, 0.5% or more, 0.6% or more, 0.7% or more, 0.8% or more, 0.9% or more, 1% or more, 1.5% or more, 2% or more, 2.5% or more, 3% or more, 3.5% or more, or 4% or more, particularly 4.5% or more. Meanwhile, when the content of B_2O_3 is too large, a depth of compression may be reduced. In particular, the efficiency of ion exchange between a Na ion in the glass and a K ion in the molten salt is liable to be reduced, and the diffusion of the K ion is liable to be reduced. Accordingly, a suitable upper limit range of the content of B_2O_3 is 15% or less, 14.5% or less, 14% or less, 13.5% or less, 13% or less, 12.5% or less, 12% or less, 11.5% or less, 11% or less, 10.5% or less, 10% or less, 9.5% or less, 9% or less, 8.5% or less, 8% or less, 7.5% or less, 7% or less, 6.5% or less, or 6% or less, particularly 5.5% or less. When the content of B_2O_3 is set to fall within the suitable ranges, it becomes easy to form the profile having the first peak "a", the first bottom "b", the second peak "c", and the second bottom "d".

[0089] Li_2O is an ion exchange component, and is particularly an essential component for obtaining a large depth of compression through ion exchange between a Li ion in the glass and a Na ion in the molten salt. In addition, Li_2O is a component that reduces the viscosity at high temperature to improve the meltability and the formability, and is also a component that increases the Young's modulus. Accordingly, a suitable lower limit range of the content of Li_2O is 0% or more, 0.1% or more, 0.5% or more, 1% or more, 1.5% or more, 2% or more, 2.5% or more, 3% or more, 3.5% or more, 4% or more, 4.3% or more, 4.5% or more, 4.7% or more, 5% or more, 5.2% or more, 5.5% or more, or 5.8% or more, particularly 6.0% or more. In addition, a suitable upper limit range of the content of Li_2O is 15% or less, 13% or less, 12% or less, 11.5% or less, 11% or less, 10.5% or less, 10% or less, 9.8% or less, 9.5% or less, 9.3% or less, 9% or less, 8.8% or less, 8.5% or less, or 8.2% or less, particularly 8.0% or less.

[0090] Na_2O is an ion exchange component, and is also a component that reduces the viscosity at high temperature to improve the meltability and the formability. In addition, Na_2O is a component that improves the devitrification resistance, and is particularly a component that suppresses devitrification caused by a reaction with alumina-based refractory. Accordingly, a suitable lower limit range of the content of Na_2O is 0% or more, 0.5% or more, 1% or more, 1.2% or more, 1.5% or more, 1.8% or more, 2% or more, 2.1% or more, 2.3% or more, 2.5% or more, 2.8% or more, 3% or more, 3.2% or more, 3.5% or more, 4% or more, 4.5% or more, 5% or more, 5.5% or more, 6% or more, or 6.5% or more, particularly 7% or more. Meanwhile, when the content of Na_2O is too large, the thermal expansion coefficient is excessively increased, and the thermal shock resistance is liable to be reduced. In addition, the glass composition loses its component balance, and the devitrification resistance may be reduced contrarily. Accordingly, a suitable upper limit range of the content of Na_2O is 25% or less, 21% or less, 20% or less, or 19% or less, particularly 18% or less, 15% or less, 13% or less, or 11% or less, particularly 10% or less.

[0091] K_2O is a component that reduces the viscosity at high temperature to improve the meltability and the formability. Further, K_2O is a component that increases the depth of compression. Accordingly, a suitable lower limit range of the content of K_2O is 0% or more, 0.01% or more, 0.02% or more, 0.03% or more, 0.05% or more, 0.08% or more, 0.1% or more, 0.2% or more, 0.3% or more, or 0.4% or more, particularly 0.5% or more. Meanwhile, when the content of K_2O is too large, the thermal expansion coefficient may be increased, and the thermal shock resistance may be reduced. In addition, a compressive stress value on the outermost surface is liable to be reduced. Accordingly, a suitable upper limit range of the content of K_2O is 10% or less, 7% or less, 6% or less, 5% or less, 4% or less, 3% or less, 2% or less, 1.5% or less, or 1% or less, particularly less than 1%.

[0092] MgO is a component that reduces the viscosity at high temperature to improve the meltability and the formability, and increases the strain point and the Vickers hardness. Among alkaline earth metal oxides, MgO is a component that has a high improving effect on the ion exchange performance. Accordingly, a suitable lower limit range of the content of MgO is 0% or more, 0.03% or more, 0.05% or more, 0.07% or more, 0.10% or more, 0.15% or more, 0.2% or more, 0.5% or more, 0.6% or more, 0.7% or more, 1.0% or more, or 1.5% or more, particularly 1.8% or more. Meanwhile, when the content of MgO is too large, the devitrification resistance is liable to be reduced. In particular, it becomes difficult to suppress devitrification caused by a reaction with alumina-based refractory. Accordingly, a suitable upper limit range of the content of MgO is 15% or less, 12% or less, 11% or less, 10% or less, 8% or less, 7% or less, 6.5% or less, 6% or less, 5.5% or less, 5% or less, 4.7% or less, 4.5% or less, 4.2% or less, 4% or less, or 3.8% or less, particularly 3.5% or less.

[0093] CaO is a component that reduces the viscosity at high temperature to improve the meltability and the formability without reducing the devitrification resistance as compared to other components, and increases the strain point and the Vickers hardness. However, when the content of CaO is too large, the ion exchange performance may be reduced, or an ion exchange solution may be degraded at the time of ion exchange treatment. Accordingly, the content of CaO is preferably from 0% to 10%, from 0% to 9%, from 0% to 8%, from 0% to 7%, from 0% to 6%, from 0% to 5.5%, from 0% to 5%, from 0% to 4.5%, from 0% to 4%, from 0% to 3.5%, from 0% to 3%, from 0% to 2%, from 0% to **18**, from 0% to less than 1%, from 0% to 0.7%, from 0% to 0.5%, from 0% to 0.3%, from 0% to 0.1%, from 0% to 0.05%, or from 0% to 0.02%, particularly preferably from 0% to less than 0.01%. When mixing of CaO as an impurity is permitted, the content of CaO is preferably 0.01% or more or 0.02% or more, particularly preferably 0.03% or more.

[0094] SrO is a component that reduces the viscosity at high temperature to improve the meltability and the formability, and increases the strain point and the Young's modulus. However, when the content of SrO is too large, an

ion exchange reaction is liable to be inhibited. Besides, the density or the thermal expansion coefficient is increased inappropriately, or the glass is liable to devitrify. Accordingly, the content of SrO is preferably from 0% to 2%, from 0% to 1.5%, from 0% to 1%, from 0% to 0.5%, or from 0% to 0.1%, particularly preferably from 0% to less than 0.1%.

[0095] BaO is a component that reduces the viscosity at high temperature to improve the meltability and the formability, and increases the strain point and the Young's modulus. However, when the content of BaO is too large, the ion exchange reaction is liable to be inhibited. Besides, the density or the thermal expansion coefficient is increased inappropriately, or the glass is liable to devitrify. Accordingly, the content of BaO is preferably from 0% to 2%, from 0% to 1.5%, from 0% to 1%, from 0% to 0.5%, or from 0% to 0.1%, particularly preferably from 0% to less than 0.1%.

[0096] ZnO is a component that improves the ion exchange performance, and is particularly a component that has a high increasing effect on the compressive stress value of the compressive stress layer on the outermost surface. In addition, ZnO is a component that reduces the viscosity at high temperature without significantly reducing a viscosity at low temperature. Meanwhile, when the content of ZnO is too large, there is a tendency that the glass undergoes phase separation, the devitrification resistance is reduced, the density is increased, or the depth of compression is reduced. Accordingly, a suitable upper limit range of the content of ZnO is 10% or less, 8% or less, 7% or less, 6% or less, 5.5% or less, 5.2% or less, 5% or less, or 4.5% or less, particularly 4% or less. A suitable lower limit range of the content of ZnO is 0% or more, 0.1% or more, 0.2% or more, 0.3% or more, 0.4% or more, 0.5% or more, 0.7% or more, 1% or more, 1.1% or more, 1.2% or more, 1.5% or more, 1.8% or more, 2.0% or more, 2.1% or more, 2.2% or more, 2.5% or more, 2.8% or more, 3.0% or more, 3.1% or more, or 3.2% or more, particularly 3.5% or more.

[0097] P_2O_5 is a component that improves the ion exchange performance, and is particularly a component that increases the depth of compression. Further, P_2O_5 is a component that improves the acid resistance. Further, P_2O_5 is a component that increases the oxygen electron constraint force exhibited by a cation to reduce the basicity of the glass. However, when the content of P_2O_5 is too large, the glass undergoes phase separation, and water resistance is liable to be reduced. In addition, the depth of compression (DOC_{Na}) obtained through ion exchange between a Li ion in the glass and a Na ion in the molten salt is excessively increased, with the result that the compressive stress value at a predetermined depth (from 5 μm to 50 μm) from the outermost surface is liable to be reduced. Accordingly, a suitable upper limit range of the content of P_2O_5 is 15% or less, 10% or less, 8% or less, 7% or less, 6% or less, 5% or less, 4.7% or less, 4.5% or less, or 4% or less, particularly 3.5% or less. When the content of P_2O_5 is set to fall within the suitable ranges, it becomes easy to form a non-monotonic profile. Meanwhile, when the content of P_2O_5 is too small, the ion exchange performance may not be sufficiently exhibited. In particular, the efficiency of ion exchange between a Na ion in the glass and a K ion in the molten salt is liable to be reduced, and the diffusion of the K ion is liable to be reduced. In addition, the glass may become unstable, and the devitrification resistance may be reduced. In addition, the basicity of the glass is excessively increased, and the release amount of O_2 through a reaction of a fining agent is reduced to reduce the bubble forming property, with the result that bubbles may remain in the glass when the glass is formed into a sheet shape. Accordingly, a suitable lower limit range of the content of P_2O_5 is 0% or more, 0.01% or more, 0.02% or more, 0.03% or more, 0.05% or more, 0.1% or more, 0.4% or more, 0.7% or more, 1% or more, 1.2% or more, 1.4% or more, 1.6% or more, 2% or more, or 2.3% or more, particularly 2.5% or more.

[0098] SnO_2 is a fining agent, and is also a component that improves the ion exchange performance. However, when the content of SnO_2 is too large, the devitrification resistance is liable to be reduced. Accordingly, a suitable lower limit range of the content of SnO_2 is 0% or more, 0.001% or more, 0.002% or more, 0.005% or more, or 0.007% or more, particularly 0.010% or more, and a suitable upper limit range thereof is 0.30% or less, 0.27% or less, 0.25% or less, 0.20% or less, 0.18% or less, 0.15% or less, 0.12% or less, 0.10% or less, 0.09% or less, 0.08% or less, 0.07% or less, 0.06% or less, 0.05% or less, 0.047% or less, 0.045% or less, 0.042% or less, 0.040% or less, 0.038% or less, 0.035% or less, 0.032% or less, 0.030% or less, 0.025% or less, or 0.020% or less, particularly 0.015% or less.

[0099] Cl is a fining agent. Particularly when Cl is used in combination with SnO_2, a bubble diameter in the glass is easily expanded, and a fining effect is easily exhibited. Meanwhile, Cl is a component that adversely affects an environment or a facility when the content thereof is too large. Accordingly, a suitable lower limit range of the content of cl is 0.001% or more, 0.005% or more, 0.008% or more, 0.010% or more, 0.015% or more, 0.018% or more, 0.019% or more, 0.020% or more, 0.023% or more, 0.025% or more, 0.027% or more, 0.030% or more, 0.035% or more, 0.040% or more, 0.050% or more, 0.07% or more, or 0.09% or more, particularly 0.10% or more, and a suitable upper limit range thereof is 0.3% or less, 0.2% or less, 0.17% or less, or 0.15% or less, particularly 0.12% or less.

[0100] MoO_3 is a component that absorbs UV light (light at a wavelength of from 200 nm to 300 nm). When MoO_3 is incorporated in the glass, an internal element of a device using the tempered glass sheet of the present invention as a cover glass can be prevented from being degraded by UV light. In addition, MoO_3 is a component that is mixed in through a manufacturing process as well. Particularly when a raw material batch is melted through electric melting heating, MoO_3 is mixed in by being eluted from a Mo electrode. The use of electric melting can reduce the amount of water in the glass. When the amount of water in the glass is reduced, a liquidus viscosity and the strain point are increased, and the devitrification resistance and heat resistance of the glass can be improved. In addition, when the strain point is increased, stress relaxation is less liable to occur, and a high compressive stress value can be maintained. When the content of MoO_3 is too small, the electric melting, which may involve mixing of MoO_3, cannot be used, and hence the above-mentioned effects are not obtained. Accordingly, a suitable lower limit range of the content of MoO_3 is 0% or more, 0.0001% or more, 0.0003% or more, 0.0005% or more, 0.0008% or more, 0.001% or more, 0.0012% or more, or 0.0015% or more, particularly 0.002% or more. Meanwhile, when the content of MoO_3 is too large, the transmittance of a cover glass is liable to be reduced. Accordingly, a suitable upper limit range of the content of MoO_3 is 0.02% or less, 0.018% or less, 0.015%

or less, 0.012% or less, 0.01% or less, 0.008% or less, 0.007% or less, 0.006% or less, or 0.005% or less, particularly less than 0.004%.

[0101] A suitable lower limit range of $[B_2O_3]+[MgO]+[CaO]$, which is the total of the contents of B_2O_3, MgO, and CaO, is 0.1% or more, 0.5% or more, 0.8% or more, 1% or more, 2% or more, 3% or more, 3.5% or more, 4% or more, 5% or more, 6% or more, or 6.5% or more, particularly 7% or more. When the value of $[B_2O_3]+[MgO]+[CaO]$ is too small, it is difficult to reduce the softening point. Meanwhile, when the value of $[B_2O_3]+[MgO]+[CaO]$ is too large, the glass may become unstable, and the devitrification resistance may be reduced. Accordingly, a suitable upper limit range of $[B_2O_3]+[MgO]+[CaO]$ is 30% or less, 28% or less, 25% or less, 24% or less, 22% or less, or 20% or less, particularly 18% or less.

[0102] A suitable lower limit range of $[Li_2O]+[Na_2O]+[K_2O]$, which is the total of the contents of Li_2O, Na_2O, and K_2O, is 7% or more, 7.5% or more, 8% or more, 8.5% or more, 8.8% or more, 9% or more, 9.5% or more, 9.7% or more, 10% or more, or 10.2% or more, particularly 10.5% or more. When the value of $[Li_2O]+[Na_2O]+[K_2O]$ is too small, the efficiency of ion exchange is liable to be reduced, and it is difficult to reduce the softening point. Meanwhile, when the value of $[Li_2O]+[Na_2O]+[K_2O]$ is too large, chemical resistance may be reduced. A suitable upper limit range of $[Li_2O]+[Na_2O]+[K_2O]$ is 30% or less, 28% or less, 25% or less, or 24% or less, particularly 23% or less.

[0103] A suitable lower limit range of $[Al_2O_3]+[Li_2O]+[Na_2O]+[K_2O]$, which is the total of the contents of Al_2O_3, Li_2O, Na_2O, and K_2O, is 10.5% or more, 11% or more, 11.5% or more, 12.0% or more, 12.3% or more, 12.5% or more, 13.0% or more, 14.0% or more, 15% or more, 16% or more, 18% or more, 19% or more, 20% or more, 21% or more, 24% or more, 25% or more, or 28% or more, particularly 30% or more. When the value of $[Al_2O_3]+[Li_2O]+[Na_2O]+[K_2O]$ is too small, the efficiency of ion exchange is liable to be reduced, and it is difficult to reduce the softening point. Meanwhile, when the value of $[Al_2O_3]+[Li_2O]+[Na_2O]+[K_2O]$ is too large, the liquidus viscosity and the chemical resistance may be reduced. A suitable upper limit range of $[Al_2O_3]+[Li_2O]+[Na_2O]+[K_2O]$ is 45% or less, 40% or less, 38% or less, or 35% or less, particularly 33% or less.

[0104] A suitable lower limit range of a molar ratio $([Li_2O]+[Na_2O]+[K_2O])/[Al_2O_3]$ is 0.5 or more, 0.6 or more, 0.7 or more, 0.75 or more, 0.8 or more, 0.85 or more, or 0.9 or more, particularly 0.95 or more. When the molar ratio $([Li_2O]+[Na_2O]+[K_2O])/[Al_2O_3]$ is too low, the efficiency of ion exchange is liable to be reduced. Meanwhile, also when the molar ratio $([Li_2O]+[Na_2O]+[K_2O])/[Al_2O_3]$ is too high, the efficiency of ion exchange is liable to be reduced. Accordingly, a suitable upper limit range of the molar ratio $([Li_2O]+[Na_2O]+[K_2O])/[Al_2O_3]$ is 2.0 or less, 1.9 or less, 1.8 or less, 1.7 or less, 1.6 or less, 1.5 or less, or 1.4 or less, particularly 1.3 or less. The molar ratio "$([Li_2O]+[Na_2O]+[K_2O])/[Al_2O_3]$" refers to a value obtained by dividing the total of the contents of Li_2O, Na_2O, and K_2O by the content of Al_2O_3.

[0105] A suitable upper limit range of a molar ratio $[Al_2O_3]/([R_2O]+[RO])$ is 1.5 or less, 1.4 or less, 1.3 or less, 1.2 or less, 1.1 or less, or 1 or less, particularly 0.9 or less. When the molar ratio $[Al_2O_3]/([R_2O]+[RO])$ is too high, the viscosity at high temperature is increased, with the result that the meltability and the formability are liable to be reduced. Meanwhile, when the molar ratio $[Al_2O_3]/([R_2O]+[RO])$ is too low, the liquidus temperature may be increased, and the liquidus viscosity may be reduced. Accordingly, a suitable lower limit range of the molar ratio $[Al_2O_3]/([R_2O]+[RO])$ is 0.2 or more, 0.25 or more, 0.3 or more, or 0.35 or more, particularly 0.4 or more. The molar ratio $[Al_2O_3]/([R_2O]+[RO])$ refers to a value obtained by dividing the content of Al_2O_3 by the total of the total content R_2O of alkali metal oxides and the total content RO of alkaline earth oxides.

[0106] A suitable upper limit range of a molar ratio $[Na_2O]/[Li_2O]$ is 1.0 or less, 0.9 or less, 0.8 or less, 0.7 or less, 0.6 or less, 0.5 or less, 0.4 or less, or 0.35 or less, particularly 0.3 or less. When the molar ratio $[Na_2O]/[Li_2O]$ is too high, the efficiency of ion exchange between a Li ion in the glass and a Na ion in the molten salt is liable to be reduced. Meanwhile, when the molar ratio $[Na_2O]/[Li_2O]$ is too low, the efficiency of ion exchange between a Na ion in the glass and a K ion in the molten salt is liable to be reduced. The molar ratio $[Na_2O]/[Li_2O]$ is preferably 0.03 or more, 0.05 or more, 0.07 or more, 0.10 or more, or 0.15 or more, particularly preferably 0.2 or more. The molar ratio $[Na_2O]/[Li_2O]$ refers to a value obtained by dividing the content of Na_2O by the content of Li_2O.

[0107] A suitable lower limit range of a molar ratio $([ZnO]+[Li_2O]+[Na_2O]+[K_2O])/[Al_2O_3]$ is 0.7 or more, 0.75 or more, 0.8 or more, 0.85 or more, or 0.9 or more, particularly 0.95 or more. When the molar ratio $([ZnO]+[Li_2O]+[Na_2O]+[K_2O])/[Al_2O_3]$ is too low, the efficiency of ion exchange is liable to be reduced, and it is difficult to reduce the softening point. Meanwhile, also when the molar ratio $([ZnO]+[Li_2O]+[Na_2O]+[K_2O])/[Al_2O_3]$ is too high, the efficiency of ion exchange is liable to be reduced. Accordingly, a suitable upper limit range of the molar ratio $([ZnO]+[Li_2O]+[Na_2O]+[K_2O])/[Al_2O_3]$ is 2 or less, 1.9 or less, 1.8 or less, 1.7 or less, 1.6 or less, 1.5 or less, or 1.4 or less, particularly 1.3 or less. The molar ratio $([ZnO]+[Li_2O]+[Na_2O]+[K_2O])/[Al_2O_3]$ refers to a value obtained by dividing the total of the contents of ZnO, Li_2O, Na_2O, and K_2O by the content of Al_2O_3.

[0108] A molar ratio $[MgO]/[Al_2O_3]$ is preferably 1.0 or less, 0.8 or less, 0.6 or less, 0.5 or less, 0.4 or less, 0.3 or less, or 0.25 or less, particularly preferably 0.2 or less. When the molar ratio $[MgO]/[Al_2O_3]$ is too high, reaction stones are liable to be generated at the time of contact with a forming body (particularly, an alumina forming body) at high temperature, with the result that the quality of the glass formed into a sheet shape may be reduced. Meanwhile, the lower limit of the molar ratio $[MgO]/[Al_2O_3]$ is not particularly limited, but is, for example, 0 or more, 0.01 or more, 0.03 or more, or 0.05 or more. The molar ratio "$[MgO]/[Al_2O_3]$" refers to a value obtained by dividing the content of MgO by the content of Al_2O_3.

[0109] When the range of a molar ratio $([SiO_2]+[B_2O_3]+[P_2O_5])/((100\times[SnO_2])\times([Li\ \mathbf{20}]+[Na_2O]+[K_2O]+[MgO]+[CaO]+[BaO]+[SrO]+[ZnO]+[Al_2O_3]))$ is restricted, the devitrification resistance can be improved while a fining property is improved. A suitable lower limit range of the molar ratio $([SiO_2]+[B_2O_3]+[P_2O_5])/((100\times[SnO_2])\times([Li_2O]+[Na_2O]+[K_2O]+[MgO]+[CaO]+[BaO]+[SrO]+[ZnO]+[Al_2O_3]))$ is 0.30 or more, 0.33 or more, 0.35 or more, 0.37 or more, 0.38 or more, 0.39 or more, 0.40 or more, 0.41 or more, 0.42 or more, 0.43 or more, 0.44 or

more, 0.45 or more, 0.48 or more, 0.50 or more, 0.51 or more, 0.52 or more, 0.53 or more, or 0.54 or more, particularly 0.55 or more. When ratio the molar $([SiO_2]+[B_2O_3]+[P_2O_5])/((100\times[SnO_2])\times([Li_2O]+[Na_2O]+[K_2O]+[MgO]+[CaO]+[BaO]+[SrO]+[ZnO]+[Al_2O_3]))$ is too low, a SnO_2 crystal is liable to be precipitated. An upper limit range of the molar ratio $([SiO_2]+[B_2O_3]+[P_2O_5])/((100\times[SnO_2])\times([Li_2O]+[Na_2O]+[K_2O]+[MgO]+[CaO]+[BaO]+[SrO]+[ZnO]+[Al_2O_3]))$ is not particularly limited, but is, for example, 4.0 or less, 3.0 or less, 2.0 or less, 1.5 or less, or 1.0 or less. The molar ratio "$([SiO_2]+[B_2O_3]+[P_2O_5])/((100\times[SnO_2])\times([Al_2O_3]+[Li_2O]+[Na_2O]+[K_2O]+[MgO]+[CaO]+[BaO]+[SrO]+[ZnO])$)" refers to a value obtained by dividing the total content of SiO_2, B_2O_3, and P_2O_5 by a value obtained by multiplying a value that is 100 times as large as the content of SnO_2 and the total content of Al_2O_3, Li_2O, Na_2O, K_2O, MgO, CaO, BaO, SrO, and ZnO together.

[0110] A suitable lower limit range of a molar ratio $[Li_2O]/([Na_2O]+[K_2O])$ is 0.1 or more, 0.3 or more, 0.5 or more, or 0.6 or more, particularly 0.7 or more. When the molar ratio $[Li_2O]/([Na_2O]+[K_2O])$ is too low, the ion exchange performance may not be sufficiently exhibited. In particular, the efficiency of ion exchange between a Li ion in the glass and a Na ion in the molten salt is liable to be reduced. Meanwhile, when the molar ratio $[Li_2O]/([Na_2O]+[K_2O])$ is too high, a devitrified crystal is liable to be precipitated in the glass, and it becomes difficult to form the glass into a sheet shape by an overflow down-draw method or the like. Accordingly, a suitable upper limit range of the molar ratio $[Li_2O]/([Na_2O]+[K_2O])$ is 10 or less, 9 or less, 8.5 or less, 8 or less, 7.5 or less, 7 or less, 6.5 or less, or 6.3 or less, particularly 6 or less. The molar ratio "$[Li_2O]/([Na_2O]+[K_2O])$" refers to a value obtained by dividing the content of Li_2O by the total content of Na_2O and K_2O.

[0111] A Q value calculated by the following equation is a factor correlated to the acid resistance. When the Q value is too low, the acid resistance is liable to be reduced. Accordingly, a suitable lower limit range of the Q value is −30 or more, −25 or more, −20 or more, −18 or more, −15 or more, −12 or more, −10 or more, or −8 or more, particularly −5 or more. Meanwhile, when the Q value is too high, the ion exchange performance may not be sufficiently exhibited. Accordingly, a suitable upper limit range of the Q value is 50 or less, 45 or less, 42 or less, or 40 or less, particularly 35 or less.

$$Q = [SiO_2] + 1.2\times[P_2O_5] - 3\times[Al_2O_3] - [B_2O_3] - 2\times[Li_2O] - 1.5\times[Na_2O] - [K_2O]$$

[0112] A suitable lower limit range of a molar ratio $[Li_2O]/[Al_2O_3]$ is 0.1 or more, 0.2 or more, 0.3 or more, 0.40 or more, 0.42 or more, 0.44 or more, 0.50 or more, 0.52 or more, or 0.55 or more, particularly 0.58 or more. When the molar ratio $[Li_2O]/[Al_2O_3]$ is too low, the ion exchange performance may not be sufficiently exhibited. In particular, the efficiency of ion exchange between a Li ion in the glass and a Na ion in the molten salt is liable to be reduced. Meanwhile, when the molar ratio $[Li_2O]/[Al_2O_3]$ is too high, a devitrified crystal is liable to be precipitated in the glass, and it becomes difficult to form the glass into a sheet shape by an overflow down-draw method or the like. Accordingly, a suitable upper limit range of the molar ratio $[Li_2O]/[Al_2O_3]$ is 2.0 or less, 1.8 or less, 1.5 or less, 1.2 or less, 1.0 or less, 0.8 or less, 0.7 or less, or 0.68 or less, particularly 0.60 or less. The molar ratio "$[Li_2O]/[Al_2O_3]$" refers to a value obtained by dividing the content of Li_2O by the content of Al_2O_3.

[0113] An X value calculated by the following equation is a factor correlated to an exchange speed between a Li ion and a Na ion. When the X value is too low, the efficiency of ion exchange between a Li ion and a Na ion in the molten salt is reduced, and it becomes difficult to produce a compressive stress. In particular, the depth of compression (DOC_{Na}) of the compressive stress layer obtained through ion exchange between a Li ion in the glass and a Na ion in the molten salt may be reduced. Accordingly, a suitable lower limit range of the X value is 300 or more, 320 or more, 330 or more, 340 or more, 350 or more, 400 or more, 450 or more, 460 or more, 480 or more, 500 or more, or 520 or more, particularly 550 or more. An upper limit range of the X value is not particularly limited, but is, for example, 900 or less or 880 or less.

$$X = -1.49\times[SiO_2] + 26.98\times[Al_2O_3] - 3.23\times[B_2O_3] + 48.56\times[Li_2O] - 24.31\times[Na_2O] - 0.28\times[MgO] + 2.74\times[CaO]$$

[0114] A Y value calculated by the following equation is a factor correlated to an exchange speed between a Na ion and a K ion. When the Y value is too low, the efficiency of ion exchange between a Na ion in the glass and a K ion in the molten salt is reduced, and it becomes difficult to produce a compressive stress. In particular, the depth of compression (DOCK) of the compressive stress layer obtained through ion exchange between a Na ion in the glass and a K ion in the molten salt may be reduced. Accordingly, a suitable lower limit range of the Y value is 4 or more, 4.3 or more, 4.5 or more, 4.8 or more, 5 or more, 5.2 or more, 5.5 or more, 6 or more, 7 or more, 8 or more, 9 or more, or 10 or more, particularly 11 or more. An upper limit range of the Y value is not particularly limited, but is, for example, 30 or less or 25 or less.

$$Y = 3 + 0.21\times[SiO_2] + 0.25\times[Al_2O_3] - 0.33\times[B_2O_3] - 0.55\times[Li_2O] + 0.45\times[Na_2O] - 0.97\times[MgO] - 1.46\times[CaO]$$

[0115] A Z value calculated by the following equation is strongly correlated to both the exchange speed between a Li ion and a Na ion and the exchange speed between a Na ion and a K ion, and is a particularly important factor when the glass sheet to be tempered is subjected to ion exchange treatment a plurality of times. When the Z value is too low, the efficiency of ion exchange between a Li ion and a Na ion in the molten salt is liable to be reduced, and also the efficiency of ion exchange between a Na ion and a K ion in the molten salt is liable to be reduced. Thus, it becomes difficult to produce a compressive stress through each of the above-mentioned two kinds of ion exchange. Accordingly, a suitable lower limit range of the Z value is 18 or more, 18.5 or more, 19 or more, 20 or more, 25 or more, 30 or more, 35 or more, or 45 or more, particularly 50 or more. An upper

limit range of the Z value is not particularly limited, but is, for example, 120 or less or 100 or less.

$$Z = 0.13 \times [SiO_2] + 2.36 \times [Al_2O_3] - 0.14 \times [B_2O_3] + 4.90 \times [Li_2O] - 5.53 \times [Na_2O] - 2.14 \times [MgO] - 2.34 \times [CaO]$$

[0116] A W value calculated by the following equation is a factor correlated to the Young's modulus. When the W value is too low, the Young's modulus is reduced, and the glass is liable to be broken. Accordingly, a suitable lower limit range of the W value is 250 or more, 300 or more, 330 or more, 340 or more, 350 or more, 360 or more, 370 or more, 400 or more, 430 or more, 450 or more, or 480 or more, particularly 500 or more. An upper limit range of the W value is not particularly limited, but is, for example, 750 or less or 700 or less.

$$W = 0.07 \times [SiO_2] + 18.17 \times [Al_2O_3] - 4.42 \times [B_2O_3] + 41.43 \times [Li_2O] - 29.30 \times [Na_2O] + 1.43 \times [MgO] - 10.43 \times [CaO]$$

[0117] A U value calculated by the following equation is a factor correlated to the fracture toughness. When the U value is too low, the fracture toughness value is reduced, and the glass is liable to be broken. Accordingly, a suitable lower limit range of the U value is 7,000 or more, 7,100 or more, 7,500 or more, 7,600 or more, 7,700 or more, 7,750 or more, 7,800 or more, or 7,850 or more, particularly 7,900 or more. An upper limit range of the U value is not particularly limited, but is, for example, 20,000 or less, 18,000 or less, 15,000 or less, 12,000 or less, 10,000 or less, or 9,500 or less.

$$U = 87.39 \times [SiO_2] + 180.12 \times [Al_2O_3] + 93.63 \times [B_2O_3] + 113.78 \times ([MgO] + [CaO] + [BaO] + [SrO]) - 46.2 \times [Li_2O] - 71.1 \times [Na_2O] - 58.6 \times [K_2O] - 40.0 \times [P_2O_5]$$

[0118] For example, the following components may be added in addition to the above-mentioned components.

[0119] TiO_2 is a component that improves the ion exchange performance, and is also a component that reduces the viscosity at high temperature. However, when the content of TiO_2 is too large, transparency and the devitrification resistance are liable to be reduced. Accordingly, a suitable content of TiO_2 is from 0% to 10%, from 0% to 5%, from 0% to 3%, from 0% to 1.5%, from 0% to 1%, or from 0% to 0.1%, particularly from 0.001% to 0.1%.

[0120] ZrO_2 is a component that increases the Vickers hardness, and is also a component that increases viscosity around the liquidus viscosity and the strain point. However, when the content of ZrO_2 is too large, the devitrification resistance may be significantly reduced. Accordingly, a suitable content of ZrO_2 is from 0% to 10%, from 0% to 5%, from 0% to 3%, from 0% to 1.5%, from 0% to 1%, from 0% to 0.5%, from 0% to 0.4%, from 0% to 0.3%, or from 0% to 0.2%, particularly from 0% to 0.1%.

[0121] La_2O_3 is a component that increases the Young's modulus and the fracture toughness. However, when the content of La_2O_3 is too large, the liquidus viscosity may be reduced. Accordingly, a suitable content of La_2O_3 is from 0% to 5%, from 0% to 3%, from 0% to 1.5%, from 0% to 1%, from 0% to 0.8%, from 0% to 0.5%, from 0% to 0.4%, from 0% to 0.3%, or from 0% to 0.2%, particularly from 0% to 0.1%.

[0122] Fe_2O_3 is an impurity that is mixed in from raw materials. A suitable upper limit range of the content of Fe_2O_3 is 0.1% or less, 0.08% or less, 0.05% or less, 0.02% or less, or less than 0.015%, less than 0.01%, or less than 0.008%, particularly less than 0.005%. When the content of Fe_2O_3 is too large, the transmittance of a cover glass is liable to be reduced. Meanwhile, a suitable lower limit range of the content of Fe_2O_3 is 0.001% or more, 0.002% or more, or 0.003% or more. When the content of Fe_2O_3 is too small, a raw material cost rises owing to the use of high-purity raw materials, and a product cannot be manufactured inexpensively.

[0123] As a fining agent, SO_3 and/or CeO_2 may be added at from 0.001% to 1%.

[0124] Rare earth oxides, such as Nd_2O_3, Y_2O_3, Nb_2O_5, Ta_2O_5, and Hf_2O_3, are each a component that increases the Young's modulus. However, raw material costs therefor are high. In addition, when the rare earth oxides are each added in a large amount, the devitrification resistance is liable to be reduced. Accordingly, a suitable total content of the rare earth oxides is 5% or less, 4% or less, 3% or less, 2% or less, 1% or less, or 0.5% or less, particularly 0.1% or less, and a suitable content of each of Nd_2O_3, Y_2O_3, Nb_2O_5, Ta_2O_5, and Hf_2O_3 is 3% or less, 2% or less, 1% or less, or 0.5% or less, particularly 0.1% or less.

[0125] The tempered glass sheet and glass sheet to be tempered of the present invention are each preferably substantially free of As_2O_3, Sb_2O_3, PbO, and F as a glass composition from the standpoint of environmental considerations. In addition, the tempered glass sheet and the glass sheet to be tempered are each preferably substantially free of Bi_2O_3 from the standpoint of environmental considerations. The phrase "substantially free of" has a concept in which the explicit component is not positively added as a glass component, but its addition at an impurity level is permitted, and specifically refers to the case in which the content of the explicit component is less than 0.05%.

[0126] The tempered glass sheet and glass sheet to be tempered of the present invention each preferably have the following characteristics.

[0127] The density (ρ) is preferably 2.55 g/cm^3 or less, 2.53 g/cm^3 or less, 2.50 g/cm^3 or less, 2.49 g/cm^3 or less, 2.48 g/cm^3 or less, 2.45 g/cm^3 or less, or from 2.35 g/cm^3 to 2.44 g/cm^3, particularly preferably from 2.25 g/cm^3 to 2.44 g/cm^3. As the density becomes lower, the weight of the tempered glass sheet can be reduced more.

[0128] A thermal expansion coefficient ($\alpha_{30\text{-}380}$° C.) at from 30° C. to 380° C. is preferably 150×10^{-7}/° C. or less, 100×10^{-7}/° C. or less, from 50×10^{-7}/° C. to 95×10^{-7}/° C., or from 40×10^{-7}/° C. to 85×10^{-7}/° C., particularly preferably from 35×10^{-7}/° C. to 80×10^{-7}/° C. The term "thermal expansion coefficient at from 30° C. to 380° C." refers to a value measured for an average thermal expansion coefficient with a dilatometer.

[0129] The softening point (Ts) is preferably 950° C. or less, 940° C. or less, 930° C. or less, 920° C. or less, 910° C. or less, 900° C. or less, 890° C. or less, 880° C. or less, 870° C. or less, 860° C. or less, 850° C. or less, 840° C. or

less, 830° C. or less, 820° C. or less, or 810° C. or less, particularly preferably from 700° C. to 800° C. When the softening point is too high, thermal processability may be reduced.

[0130] A temperature ($10^{2.5}$ dPa·s) at a viscosity at high temperature of $10^{2.5}$ dPa·s is preferably 1, 680° C. or less, 1, 670° C. or less, 1,660° C. or less, 1,650° C. or less, 1,640° C. or less, 1,630° C. or less, 1,620° C. or less, 1,600° C. or less, 1,550° C. or less, 1,520° C. or less, or 1,500° C. or less, particularly preferably from 1,300° C. to 1, 490° C. When the temperature at a viscosity at high temperature of $10^{2.5}$ dPa·s is too high, the meltability and the formability are reduced, and it becomes difficult to form molten glass into a sheet shape.

[0131] The liquidus viscosity is preferably $10^{3.74}$ dPa·s or more, $10^{4.3}$ dPa·s or more, $10^{4.4}$ dPa·s or more, $10^{4.5}$ dPa·s or more, $10^{4.6}$ dPa·s or more, $10^{4.7}$ dPa·s or more, $10^{4.8}$ dPa·s or more, $10^{4.9}$ dPa·s or more, $10^{5.0}$ dPa·s or more, $10^{5.1}$ dPa·s or more, $10^{5.2}$ dPa·s or more, $10^{5.3}$ dPa·s or more, or $10^{5.4}$ dPa·s or more, particularly preferably $10^{5.5}$ dPa·s or more. As the liquidus viscosity becomes higher, the devitrification resistance is improved more, and devitrified stones are less liable to be generated at the time of forming. The term "liquidus viscosity" as used herein refers to a value measured for a viscosity at a liquidus temperature by a platinum sphere pull up method.

[0132] The Young's modulus (E) is preferably 60 GPa or more, 65 GPa or more, 70 GPa or more, 71 GPa or more, 72 GPa or more, 73 GPa or more, or 74 GPa or more, particularly preferably 75 GPa or more. When the Young's modulus is low, a cover glass is liable to be deflected when its sheet thickness is small. In addition, an upper limit range of the Young's modulus is not particularly limited, but is substantially 100 GPa or less. The "Young's modulus" may be calculated by a well-known resonance method.

[0133] The tempered glass sheet of the present invention has a compressive stress layer in a surface thereof. The compressive stress value (CS) of the compressive stress layer on the outermost surface of the tempered glass sheet is preferably 200 MPa or more, 220 MPa or more, 250 MPa or more, 280 MPa or more, 300 MPa or more, 310 MPa or more, 320 MPa or more, 330 MPa or more, 340 MPa or more, 350 MPa or more, 360 MPa or more, 370 MPa or more, 380 MPa or more, 390 MPa or more, 400 MPa or more, 420 MPa or more, or 430 MPa or more, particularly preferably 450 MPa or more. As the compressive stress value (CS) of the compressive stress layer on the outermost surface becomes higher, the Vickers hardness is increased more. Meanwhile, when an excessively large compressive stress is formed in the surface, the internal tensile stress of the tempered glass sheet may be increased excessively, and a dimensional change before and after ion exchange treatment may be increased. Accordingly, the compressive stress value (CS) of the compressive stress layer on the outermost surface is preferably 1,400 MPa or less, 1,200 MPa or less, 1, 100 MPa or less, 1,000 MPa or less, 900 MPa or less, 700 MPa or less, 680 MPa or less, or 650 MPa or less, particularly preferably 600 MPa or less. There is a tendency that the compressive stress value of the compressive stress layer on the outermost surface is increased when an ion exchange time period is shortened, or the temperature of an ion exchange solution is reduced.

[0134] The compressive stress value (CS30) of the tempered glass sheet at a depth of 30 μm from the outermost surface is preferably 35 MPa or more, 40 MPa or more, 50 MPa or more, 60 MPa or more, 70 MPa or more, 80 MPa or more, 90 MPa or more, 100 MPa or more, 105 MPa or more, 110 MPa or more, or 115 MPa or more, particularly preferably 120 MPa or more. As the compressive stress value (CS30) at a depth of 30 μm from the outermost surface becomes higher, the strength of the tempered glass sheet is increased more. Meanwhile, when an excessively large compressive stress is formed at a depth of 30 μm from the outermost surface, the internal tensile stress of the tempered glass sheet may be increased excessively, and a dimensional change before and after the ion exchange treatment may be increased. Accordingly, the compressive stress value (CS30) at a depth of 30 μm from the outermost surface is preferably 400 MPa or less, 350 MPa or less, 300 MPa or less, 250 MPa or less, 230 MPa or less, 220 MPa or less, 210 MPa or less, 205 MPa or less, 200 MPa or less, or 195 MPa or less, particularly preferably 190 MPa or less.

[0135] The compressive stress value (CS50) of the tempered glass sheet at a depth of 50 μm from the outermost surface is preferably 20 MPa or more, 30 MPa or more, 40 MPa or more, 50 MPa or more, 60 MPa or more, 70 MPa or more, 80 MPa or more, 90 MPa or more, or 95 MPa or more, particularly preferably 100 MPa or more. As the compressive stress value (CS50) at a depth of 50 μm from the outermost surface becomes higher, the strength of the tempered glass sheet is increased more. Meanwhile, when an excessively large compressive stress is formed at a depth of 50 μm from the outermost surface, the internal tensile stress of the tempered glass sheet may be increased excessively, and a dimensional change before and after the ion exchange treatment may be increased. Accordingly, the compressive stress value (CS50) at a depth of 50 μm from the outermost surface is preferably 380 MPa or less, 350 MPa or less, 300 MPa or less, 250 MPa or less, 220 MPa or less, 210 MPa or less, 200 MPa or less, 195 MPa or less, 190 MPa or less, or 180 MPa or less, particularly preferably 170 MPa or less.

[0136] The internal tensile stress value (CT) of the tempered glass sheet is preferably 150 MPa or less, 130 MPa or less, 120 MPa or less, 110 MPa or less, 100 MPa or less, 90 MPa or less, 85 MPa or less, 80 MPa or less, 75 MPa or less, 70 MPa or less, or 60 MPa or less, particularly preferably 50 MPa or less. When the internal tensile stress value is too high, the tempered glass sheet may undergo self-destruction by point collision. An upper limit range of the internal tensile stress value (CT) is not particularly limited, but is substantially 5 μm or more.

[0137] The depth of compression of the compressive stress layer of the tempered glass sheet, that is, a depth (DOC) at which the stress value becomes zero is preferably 3 μm or more, 5 μm or more, 10 μm or more, 20 μm or more, 30 μm or more, 40 μm or more, 45 μm or more, 50 μm or more, 55 μm or more, 58 μm or more, 60 μm or more, 65 μm or more, 70 μm or more, 75 μm or more, 80 μm or more, or 85 μm or more, particularly preferably 90 μm or more. As the depth of compression becomes larger, protrusions or sand grains on a road surface are less liable to reach a tensile stress layer at the time of dropping of a smartphone, and thus the breakage probability of a cover glass can be reduced more. Meanwhile, when the depth of compression is too large, a dimensional change before and after the ion exchange treatment may be increased. Further, there is a tendency that the compressive stress value on the outermost surface is reduced. Accordingly, the depth of compression (DOC) is

preferably 200 μm or less, 180 μm or less, 150 μm or less, 140 μm or less, 135 μm or less, 130 μm or less, or 125 μm or less, particularly preferably 120 μm or less, particularly more preferably 110 μm or less. There is a tendency that the depth of compression is increased when the ion exchange time period is prolonged, or the temperature of the ion exchange solution is increased.

[0138] In addition, a compressive stress value (CSK) on the outermost surface, which is obtained through ion exchange between a Na ion in the glass and a K ion in the molten salt when the glass sheet to be tempered is subjected to ion exchange treatment by being immersed in a KNO_3 molten salt at 430° C. for 4 hours, is preferably 200 MPa or more, 220 MPa or more, 250 MPa or more, 280 MPa or more, 300 MPa or more, 310 MPa or more, 320 MPa or more, 330 MPa or more, 340 MPa or more, 350 MPa or more, 360 MPa or more, 370 MPa or more, 380 MPa or more, 390 MPa or more, 400 MPa or more, 420 MPa or more, or 430 MPa or more, particularly preferably 450 MPa or more. As the compressive stress value on the outermost surface becomes higher, the Vickers hardness is increased more. Meanwhile, when an excessively large compressive stress is formed in the surface, the internal tensile stress of the tempered glass sheet may be increased excessively, and a dimensional change before and after the ion exchange treatment may be increased. Accordingly, the compressive stress value (CS) on the outermost surface is preferably 1,400 MPa or less, 1,200 MPa or less, 1,100 MPa or less, 1,000 MPa or less, 900 MPa or less, 700 MPa or less, 680 MPa or less, or 650 MPa or less, particularly preferably 600 MPa or less. There is a tendency that the compressive stress value on the outermost surface is increased when the ion exchange time period is shortened, or the temperature of the ion exchange solution is reduced.

[0139] A depth of layer (DOL_K), which is obtained through ion exchange between a Na ion in the glass and a K ion in the molten salt when the glass sheet to be tempered is subjected to ion exchange treatment by being immersed in a KNO_3 molten salt at 430° C. for 4 hours, is preferably 3 μm or more, 4 μm or more, 4.5 μm or more, 5 μm or more, 6 μm or more, 7 μm or more, 8 μm or more, or 9 μm or more, particularly preferably 10 μm or more. As the depth of layer becomes larger, protrusions or sand grains on a road surface are less liable to reach the tensile stress layer at the time of dropping of a smartphone, and thus the breakage probability of a cover glass can be reduced more. Meanwhile, when the depth of layer is too large, a dimensional change before and after the ion exchange treatment may be increased. Further, there is a tendency that the compressive stress value on the outermost surface is reduced. Accordingly, the depth of layer (DOL_K) is preferably 40 μm or less, 35 μm or less, 30 μm or less, 28 μm or less, 25 μm or less, 23 μm or less, or 20 μm or less, particularly preferably 18 μm or less. There is a tendency that the depth of layer is increased when the ion exchange time period is prolonged, or the temperature of the ion exchange solution is increased.

[0140] Further, a compressive stress value (CS_{Na}) on the outermost surface, which is obtained through ion exchange between a Li ion in the glass and a Na ion in the molten salt when the glass sheet to be tempered is subjected to ion exchange treatment by being immersed in a $NaNO_3$ molten salt at 380° C. for 1 hour, is preferably 140 MPa or more, 150 MPa or more, 160 MPa or more, 170 MPa or more, 180 MPa or more, or 190 MPa or more, particularly preferably 200 MPa or more. As the compressive stress value on the outermost surface becomes higher, the strength of the tempered glass sheet is increased more. Meanwhile, when an excessively large compressive stress is formed in the surface, the internal tensile stress of the tempered glass sheet is increased excessively, and a dimensional change before and after the ion exchange treatment may be increased. Accordingly, the compressive stress value (CS_{Na}) of the compressive stress layer on the outermost surface is preferably 650 MPa or less, 630 MPa or less, 600 MPa or less, 580 MPa or less, 560 MPa or less, 550 MPa or less, 540 MPa or less, 530 MPa or less, 500 MPa or less, 480 MPa or less, 450 MPa or less, 430 MPa or less, 400 MPa or less, or 380 MPa or less, particularly preferably 350 MPa or less.

[0141] A compressive stress value (CS30Na) at a depth of 30 μm from the outermost surface, which is obtained through ion exchange between a Li ion in the glass and a Na ion in the molten salt when the glass sheet to be tempered is subjected to ion exchange treatment by being immersed in a $NaNO_3$ molten salt at 380° C. for 1 hour, is preferably 35 MPa or more, 40 MPa or more, 50 MPa or more, 60 MPa or more, 70 MPa or more, 80 MPa or more, 90 MPa or more, 100 MPa or more, 105 MPa or more, 110 MPa or more, or 115 MPa or more, particularly preferably 120 MPa or more. As the compressive stress value (CS30Na) at a depth of 30 μm from the outermost surface becomes higher, the strength of the tempered glass sheet is increased more. Meanwhile, when an excessively large compressive stress is formed at a depth of 30 μm from the outermost surface, the internal tensile stress of the tempered glass sheet is increased excessively, and a dimensional change before and after the ion exchange treatment may be increased. Accordingly, the compressive stress value (CS30Na) at a depth of 30 μm from the outermost surface is preferably 400 MPa or less, 350 MPa or less, 300 MPa or less, 250 MPa or less, 230 MPa or less, 220 MPa or less, 210 MPa or less, 205 MPa or less, 200 MPa or less, or 195 MPa or less, particularly preferably 190 MPa or less.

[0142] A depth of compression (DOC_{Na}), which is obtained through ion exchange between a Li ion in the glass and a Na ion in the molten salt when the glass sheet to be tempered is subjected to ion exchange treatment by being immersed in a $NaNO_3$ molten salt at 380° C. for 1 hour, is preferably 3 μm or more, 5 μm or more, 10 μm or more, 20 μm or more, 30 μm or more, 40 μm or more, 45 μm or more, 50 μm or more, 55 μm or more, 58 μm or more, 60 μm or more, 65 μm or more, 70 μm or more, 75 μm or more, 80 μm or more, or 85 μm or more, particularly preferably 90 μm or more. As the depth of compression becomes larger, protrusions or sand grains on a road surface are less liable to reach the tensile stress layer at the time of dropping of a smartphone, and thus the breakage probability of the cover glass can be reduced more. Meanwhile, when the depth of compression is too large, a dimensional change before and after the ion exchange treatment may be increased. Further, there is a tendency that the compressive stress value of the compressive stress layer on the outermost surface is reduced. Accordingly, the depth of compression (DOC_{Na}) is preferably 200 μm or less, 180 μm or less, 150 μm or less, 140 μm or less, 130 μm or less, or 120 μm or less, particularly preferably 110 μm or less. There is a tendency that the depth of compression is increased when the ion exchange time period is prolonged, or the temperature of the ion exchange solution is increased.

[0143] An internal tensile stress value ($CTcv_{Na}$), which is obtained through ion exchange between a Li ion in the glass and a Na ion in the molten salt when the glass sheet to be tempered is subjected to ion exchange treatment by being immersed in a $NaNO_3$ molten salt at 380° C. for 1 hour, is preferably 150 MPa or less, 130 MPa or less, 120 MPa or less, 110 MPa or less, 100 MPa or less, 90 MPa or less, 85 MPa or less, 80 MPa or less, 75 MPa or less, 70 MPa or less, or 60 MPa or less, particularly preferably 50 MPa or less. When the internal tensile stress value is too high, the tempered glass sheet may undergo self-destruction by point collision. An upper limit range of the internal tensile stress value ($CTcv_{Na}$) is not particularly limited, but is substantially 5 μm or more.

[0144] A ratio DOC_{Na}/DOL_K between the depth of compression (DOC_{Na}), which is obtained through ion exchange between a Li ion in the glass and a Na ion in the molten salt when the glass sheet to be tempered is subjected to ion exchange treatment by being immersed in a $NaNO_3$ molten salt at 380° C. for 1 hour, and the depth of layer (DOL_K), which is obtained through ion exchange between a Na ion in the glass and a K ion in the molten salt when the glass sheet to be tempered is subjected to ion exchange treatment by being immersed in a KNO_3 molten salt at 430° C. for 4 hours, is preferably 15 or less, 12 or less, 10 or less, 9 or less, 8 or less, 7.5 or less, 7.0 or less, 6.5 or less, 6.0 or less, 5.5 or less, 5.0 or less, or 4.5 or less. When the ratio DOC_{Na}/DOL_K is too high, the compressive stress value (CS30) of the tempered glass sheet, which has been subjected to two-step tempering by being immersed in a $NaNO_3$ molten salt and then immersed in a KNO_3 molten salt, at a depth of 30 μm from the outermost surface may be reduced. Meanwhile, when the ratio DOC_{Na}/DOL_K is too low, a time period required for ion exchange between a Li ion in the glass and a Na ion in the molten salt may be excessively prolonged.

[0145] A mass loss of the tempered glass sheet of the present invention per unit surface area when the tempered glass sheet is immersed in a 5 mass % HCl aqueous solution warmed to 80° C. for 24 hours is preferably 2.0 mg/cm^2 or less, 1.5 mg/cm^2 or less, 1.0 mg/cm^2 or less, or 0.8 mg/cm^2 or less, particularly preferably 0.5 mg/cm^2 or less. The tempered glass sheet may be brought into contact with an acidic chemical solution depending on a use environment of a device, and hence preferably has high acid resistance from the viewpoint of preventing a failure of the device.

[0146] In addition, a mass loss of the tempered glass sheet per unit surface area when the tempered glass sheet is immersed in a 5 mass % NaOH aqueous solution warmed to 80° C. for 6 hours is preferably 5.0 mg/cm^2 or less, 4.5 mg/cm^2 or less, 4.0 mg/cm^2 or less, 3.5 mg/cm^2 or less, or 3.0 mg/cm^2 or less, particularly preferably 2.0 mg/cm^2 or less. The tempered glass sheet may be brought into contact with an alkaline chemical solution or a detergent depending on a use environment of a device, and is hence required to have high alkali resistance.

[0147] The fracture toughness K1c is preferably 0.75 $MPa \cdot m^{0.5}$ or more, 0.78 $MPa \cdot m^{0.5}$ or more, 0.79 $MPa \cdot m^{0.5}$ or more, 0.80 $MPa \cdot m^{0.5}$ or more, or 0.81 $MPa \cdot m^{0.5}$ or more, particularly preferably 0.82 $MPa \cdot m^{0.5}$ or more. When the fracture toughness K1c is low, the tempered glass sheet is liable to be broken. The upper limit of the fracture toughness is not particularly limited, but is realistically 10 MPa·m°0.5 or less.

[0148] The fracture energy γ is energy per unit fracture area consumed at the time of fracture, and is energy calculated by the equation: $\gamma=(K1c)^2/E$. The fracture energy γ is preferably 5.0 J/m^2 or more, 5.5 J/m^2 or more, 6.0 J/m^2 or more, 6.5 J/m^2 or more, 7.0 J/m^2 or more, 7.5 J/m^2 or more, or 7.8 J/m^2 or more, particularly preferably 8.0 J/m^2 or more. When the fracture energy γ is low, the tempered glass sheet is liable to be shattered at the time of breakage, and it becomes difficult to secure safety. The upper limit of the fracture energy is not particularly limited, but is realistically 30 J/m^2 or less.

[0149] The abraded four-point bending strength of the tempered glass sheet of the present invention is preferably 150 MPa or more, 160 MPa or more, 170 MPa or more, 175 MPa or more, 180 MPa or more, 185 MPa or more, 190 MPa or more, or 195 MPa or more, particularly preferably 200 MPa or more. When the abraded four-point bending strength is too low, the tempered glass sheet is liable to be broken at the time of dropping when used as a cover glass of a smartphone. The upper limit of the abraded four-point bending strength is not particularly limited, but is realistically 1,500 MPa or less.

[0150] The tempered glass sheet of the present invention has a thickness of preferably 2.0 mm or less, 1.5 mm or less, 1.3 mm or less, 1.1 mm or less, 1.0 mm or less, or 0.9 mm or less, particularly preferably 0.8 mm or less. As the thickness becomes smaller, the mass of the tempered glass sheet can be reduced more. Meanwhile, when the thickness is too small, it becomes difficult to obtain desired mechanical strength. Accordingly, the thickness is preferably 0.03 mm or more, 0.05 mm or more, 0.1 mm or more, 0.2 mm or more, 0.3 mm or more, 0.4 mm or more, 0.5 mm or more, or 0.6 mm or more, particularly preferably 0.7 mm or more.

[0151] A method of manufacturing a tempered glass sheet of the present invention comprises: a preparation step of preparing a glass sheet to be tempered including as a glass composition, in terms of mol %, 50% to 80% of SiO_2, 7% to 25% of Al_2O_3, 0% to 15% of B_2O_3, 0% to 15% of Li_2O, 0% to 25% of Na_2O, 0% to 10% of K_2O, 0% to 15% of MgO, 0% to 10% of CaO, 0% to 10% of BaO, 0% to 10% of SrO, 0% to 10% of ZnO, 0% to 15% of P_2O_5, 0% to 10% of TiO_2, 0% to 10% of ZrO_2, and 0% to 0.30% of SnO_2, having a value of $[B_2O_3]+[MgO]+[CaO]$ of from 0.1% to 30%, and having a value of $([Li_2O]+[Na_2O]+[K_2O])/[Al_2O_3]$ of from 0.5 to 2.0; and an ion exchange step of subjecting the glass sheet to be tempered to ion exchange treatment to provide a tempered glass sheet having a compressive stress layer in a surface thereof. The method of manufacturing a tempered glass sheet of the present invention encompasses not only the case of performing the ion exchange treatment a plurality of times, but also the case of performing the ion exchange treatment only once.

[0152] The method of manufacturing a glass to be tempered is, for example, as described below. As a preferred method, first, glass raw materials blended so as to give a desired glass composition are loaded into a continuous melting furnace, are heated to be melted at from 1,400° C. to 1,700° C., and are fined. After that, the molten glass is supplied to a forming apparatus and formed into a sheet shape, followed by cooling. A well-known method may be adopted as a method of cut processing, into predetermined dimensions, the glass having been formed into a sheet shape.

[0153] A method of forming the molten glass into a sheet shape is preferably an overflow down-draw method. In the

overflow down-draw method, a glass sheet to be obtained has an overflow-merged surface parallel to a main surface in the inside thereof, and a surface to serve as the surface of the glass sheet is not brought into contact with the surface of the forming body refractory, and is formed into a sheet shape in a state of a free surface. Thus, a glass sheet having satisfactory surface quality can be manufactured inexpensively without polishing. Further, in the overflow down-draw method, alumina-based refractory, zircon-based refractory, or zirconia-based refractory is used as the forming body refractory. Moreover, the tempered glass sheet and the glass sheet to be tempered of the present invention each have good compatibility with the alumina-based refractory or the zirconia-based refractory (particularly the alumina-based refractory), and hence have a property of hardly generating bubbles, stones, or the like through a reaction with the refractory.

[0154] Various forming methods may be adopted in addition to the overflow down-draw method. For example, forming methods, such as a float method, a down-draw method (e.g., a slot down-draw method or a re-draw method), a roll out method, and a press method, may be adopted.

[0155] At the time of forming of the molten glass, the molten glass is preferably cooled in a temperature region of from the annealing point of the molten glass to the strain point thereof at a cooling rate of 3° C./min or more and less than 1,000° C./min. A lower limit range of the cooling rate is preferably 10° C./min or more, 20° C./min or more, or 30° C./min or more, particularly preferably 50° C./min or more, and an upper limit range thereof is preferably less than 1,000° C./min or less than 500° C./min, particularly preferably less than 300° C./min. When the cooling rate is too high, the structure of the glass becomes coarse, and it becomes difficult to increase the Vickers hardness after the ion exchange treatment. Meanwhile, when the cooling rate is too low, the production efficiency of the glass sheet is reduced.

[0156] In the method of manufacturing a tempered glass sheet of the present invention, the ion exchange treatment may be performed a plurality of times. As the ion exchange treatment performed a plurality of times, it is preferred to perform ion exchange treatment in which the glass sheet to be tempered is immersed in a molten salt containing a KNO_3 molten salt and/or a $NaNO_3$ molten salt, and then perform ion exchange treatment in which the glass sheet to be tempered is immersed in a molten salt containing a KNO_3 molten salt and/or a $NaNO_3$ molten salt. With this configuration, the compressive stress value of the compressive stress layer on the outermost surface can be increased while a large depth of compression is ensured.

[0157] In particular, in the method of manufacturing a tempered glass sheet of the present invention, it is preferred to perform ion exchange treatment (first ion exchange step) in which the glass sheet to be tempered is immersed in a $NaNO_3$ molten salt or a mixed molten salt of $NaNO_3$ and KNO_3, and then perform ion exchange treatment (second ion exchange step) in which the glass sheet to be tempered is immersed in a mixed molten salt of KNO_3 and $LiNO_3$. With this configuration, a non-monotonic stress profile (stress distribution of the glass sheet in a thickness direction) as illustrated in FIG. **1** is easily formed. FIG. **1** is a schematic view of a stress profile obtained by measuring a stress of the tempered glass sheet from a surface in a depth direction, with a compressive stress being a positive number and a tensile stress being a negative number. FIG. **2** is an enlarged view of a low compressive stress region in the stress profile of FIG. **1**. Specifically, the stress profile having the first peak "a", the first bottom "b", the second peak "c", and the second bottom "d" can be formed. As a result, the breakage probability of a cover glass can be significantly reduced at the time of dropping of a smartphone.

[0158] In the present invention, the first peak, the first bottom, the second peak, and the second bottom are defined as described below. Herein, "a" at which the compressive stress becomes the maximum value on the surface is defined as the first peak, "b" at which the stress becomes the local minimum value after having been gradually reduced from the first peak in the depth direction is defined as the first bottom, "c" at which the compressive stress becomes the local maximum value after having been gradually increased from the first bottom in the depth direction is defined as the second peak, and "d" at which the tensile stress becomes the minimum value after having been gradually reduced from the second peak in the depth direction is defined as the second bottom.

[0159] In the first ion exchange step, a Li ion in the glass and a Na ion in the molten salt are ion exchanged with each other, and in the case of using the mixed molten salt of $NaNO_3$ and KNO_3, a Na ion in the glass and a K ion in the molten salt are further ion exchanged with each other. In this case, the ion exchange between a Li ion in the glass and a Na ion in the molten salt is faster and more efficient than the ion exchange between a Na ion in the glass and a K ion in the molten salt. In the second ion exchange step, a Na ion in the vicinity of the glass surface (a shallow region from the outermost surface to 20% of a sheet thickness) and a Li ion in the molten salt are ion exchanged with each other, and besides, a Na ion in the vicinity of the glass surface (the shallow region from the outermost surface to 20% of the sheet thickness) and a K ion in the molten salt are ion exchanged with each other. That is, in the second ion exchange step, while a Na ion in the vicinity of the glass surface is released, a K ion, which has a large ionic radius, can be introduced. As a result, the compressive stress value of the compressive stress layer on the outermost surface can be increased while a large depth of compression is maintained.

[0160] In the first ion exchange step, the temperature of the molten salt is preferably from 360° C. to 400° C., and the ion exchange time period is preferably from 30 minutes to 10 hours. In the second ion exchange step, the temperature of the ion exchange solution is preferably from 370° C. to 400° C., and the ion exchange time period is preferably from 15 minutes to 3 hours.

[0161] In order to form the non-monotonic stress profile, it is preferred that the concentration of $NaNO_3$ be higher than the concentration of KNO_3 in the mixed molten salt of $NaNO_3$ and KNO_3 to be used in the first ion exchange step, and that the concentration of KNO_3 be higher than the concentration of $LiNO_3$ in the mixed molten salt of KNO_3 and $LiNO_3$ to be used in the second ion exchange step.

[0162] In the mixed molten salt of $NaNO_3$ and KNO_3 to be used in the first ion exchange step, the concentration of KNO_3 is preferably 0 mass % or more, 0.5 mass % or more, 1 mass % or more, 5 mass % or more, 7 mass % or more, 10 mass % or more, or 15 mass % or more, particularly preferably from 20 mass % to 90 mass %. When the

concentration of KNO_3 is too high, the compressive stress value obtained through ion exchange between a Li ion in the glass and a Na ion in the molten salt may be excessively reduced. In addition, when the concentration of KNO_3 is too low, measurement of a stress with a surface stress meter FSM-6000 may become difficult.

[0163] In the mixed molten salt of KNO_3 and $LiNO_3$ to be used in the second ion exchange step, the concentration of $LiNO_3$ is preferably from 0 mass % to 5 mass %, from 0.1 mass % to 3 mass %, or from 0.15 mass % to 2 mass %, particularly preferably from 0.2 mass % to 1.5 mass %. When the concentration of $LiNO_3$ is too low, it becomes difficult to release a Na ion in the vicinity of the glass surface. Meanwhile, when the concentration of $LiNO_3$ is too high, the compressive stress value obtained through ion exchange between a Na ion in the vicinity of the glass surface and a K ion in the molten salt may be excessively reduced.

[0164] A molten salt of 100% KNO_3 free of $LiNO_3$ may be used as the molten salt to be used in the second ion exchange step. In this case, an inflected stress profile without the first bottom "b" and the second peak "c", specifically, a stress profile having an inflection point "e" as illustrated in FIG. **3** is easily obtained.

[0165] In addition, in the method of manufacturing a tempered glass sheet of the present invention, ion exchange treatment in which the glass sheet to be tempered is immersed in the mixed molten salt of $NaNO_3$ and KNO_3 once, and the second ion exchange step is not performed may be used. When the above-mentioned ion exchange treatment is performed, the stress profile having an inflection point ("e" of FIG. **3**) can be efficiently formed. When the stress profile having the inflection point "e" is formed, a glass having a high compressive stress on the surface and a large depth of compression is easily obtained. For example, when the stress profile can be approximated to a polyline formed of two straight lines, the inflection point "e" may be determined as a point on the stress profile at a depth corresponding to the intersection point between the two straight lines (inflection point of the polyline). For example, a well-known method such as a least squares method may be used for the approximation of a line.

[0166] The depth (De) of the inflection point "e" is preferably a shallow position closer to the surface. Specifically, the depth (De) of the inflection point "e" is preferably 30 μm or less, 25 μm or less, or 20 μm or less, particularly preferably 18 μm or less from the surface. Meanwhile, when the depth (De) of the inflection point "e" is too small, protrusions or sand grains on a road surface may be liable to reach the tensile stress layer at the time of dropping of a smartphone. Accordingly, the depth (De) of the inflection point "e" is preferably 3 μm or more, 4 μm or more, or 4.5 μm or more, particularly preferably 5 μm or more. In addition, the compressive stress at the inflection point is preferably 80 MPa or more, particularly preferably 100 MPa or more.

[0167] A suitable upper limit range of a Na ion (substantially, Na ion-Li ion) mutual diffusion coefficient D_{Na} at 380° C. is 1×10^{-11} m^2 sec^{-1} or less, 0.8×10^{-11} m^2 sec^{-1} or less, 0.5×10^{-11} m^2 sec^{-1} or less, or 1×10^{-12} m^2 sec^{-1} or less. When the mutual diffusion coefficient D_{Na} is too high, the diffusion of a Na ion is too fast, and the compressive stress value of the glass sheet in a relatively deep region in a thickness direction is liable to be reduced. Meanwhile, a suitable lower limit range of the Na ion mutual diffusion coefficient D_{Na} is 1×10^{-14} m^2 sec^{-1} or more, 0.5×10^{-13} m^2 sec^{-1} or more, 1×10^{-13} m^2 sec^{-1} or more, 2×10^{-13} m^2 sec^{-1} or more, 3×10^{-13} m^2 sec^{-1} or more, or 5×10^{-13} m^2 sec^{-1} or more, particularly 8×10^{-13} m^2 sec^{-1} or more. When the Na ion mutual diffusion coefficient D_{Na} is too low, a Na ion hardly diffuses, and it becomes difficult to obtain a large depth of compression (DOC). In addition, mutual diffusion between a Na ion and a Li ion hardly occurs, and it becomes difficult to form the non-monotonic stress profile.

[0168] A suitable upper limit range of a K ion (substantially, K ion-Na ion) mutual diffusion coefficient D_K at 380° C. is 1×10^{-14} m^2 sec^{-1} or less, 0.8×10^{-14} m^2 sec^{-1} or less, 0.5×10^{-14} m^2 sec^{-1} or less, 1×10^{-15} m^2 sec^{-1} or less, 0.8×10^{-15} m^2 sec^{-1} or less, 0.5×10^{-15} m^2 sec^{-1} or less, or 0.3×10^{-15} m^2 sec^{-1} or less, particularly 0.2×10^{-15} m^2 sec^{-1} or less. When the K ion mutual diffusion coefficient D_K is too high, the diffusion of a K ion is too fast, and the compressive stress value of the glass sheet in a relatively shallow region in the thickness direction is liable to be reduced. Meanwhile, a suitable lower limit range of the K ion mutual diffusion coefficient D_K is 1×10^{-17} m^2 sec^{-1} or more, 0.5×10^{-16} m^2 sec^{-1} or more, 1×10^{-16} m^2 sec^{-1} or more, 2×10^{-16} m^2 sec^{-1} or more, 3×10^{-16} m^2 sec^{-1} or more, 5×10^{-16} m^2 sec^{-1} or more, or 7×10^{-16} m^2 sec^{-1} or more, particularly 8×10^{-16} m^2 sec^{-1} or more. When the K ion mutual diffusion coefficient D_K is too low, a K ion hardly diffuses, and the depth of layer (DOL_K) of the compressive stress layer obtained through ion exchange with a K ion may be reduced.

[0169] A suitable lower limit range of a mutual diffusion coefficient ratio D_K/D_{Na} at 380° C. is 0.0001 or more, 0.0003 or more, 0.0005 or more, 0.0008 or more, 0.0010 or more, 0.0012 or more, 0.0013 or more, 0.0014 or more, 0.0015 or more, 0.0016 or more, or 0.0017 or more, particularly 0.0018 or more. When the ratio D_K/D_{Na} is too low, the diffusion speed of a K ion is too slow with respect to the diffusion speed of a Na ion, and hence the Na ion excessively diffuses in the deep region, with the result that the compressive stress value (CS30Na) at a depth of 30 μm may be reduced. The upper limit of the ratio D_K/D_{Na} is 0.0100 or less, 0.0080 or less, 0.0050 or less, 0.0040 or less, or 0.0030 or less. When the ratio D_K/D_{Na} is too low, it becomes difficult to form the non-monotonic stress profile.

[0170] The Na ion mutual diffusion coefficient D_{Na} at 380° C. may be calculated by using the following equation of [Math. 1] based on a Na ion concentration profile (concentration distribution) in the thickness direction of the tempered glass sheet having been subjected to ion exchange with a molten salt of $NaNO_3$ (100%) at 380° C. In the equation of [Math. 1], the diffusion coefficient is defined assuming that an alkali metal ion to be ion exchanged diffuses in the glass according to a complementary error function, which is an analytical solution of a diffusion equation. The Na ion concentration profile may be obtained by using EPMA measurement of a cross section of the tempered glass sheet. In the equation of [Math. 1], "x" represents a depth from the surface, C(x) represents a concentration at a depth of "x", C_{min} represents a minimum concentration, C_{max} represents a maximum concentration, "t" represents a diffusion time period, and D represents the mutual diffusion coefficient. The mutual diffusion coefficient D may be determined as a solution by substituting the results of the EPMA measurement into the equation of [Math. 1], and performing an operation assuming that the results of the

measurement fit to the complementary error function. The diffusion time period "t" substantially coincides with the ion exchange time period.

[Math. 1]

$$\frac{C(x)-C_{min}}{C_{max}-C_{min}}=\mathrm{erfc}\left(\frac{x}{\sqrt{4\tilde{D}t}}\right)$$

[0171] The K ion mutual diffusion coefficient D_K at 380° C. may be calculated by using the above-mentioned equation of [Math. 1] based on a K ion concentration profile (concentration distribution) in the thickness direction of the tempered glass sheet having been subjected to ion exchange with a molten salt of KNO_3 (100%) at 380° C. The K ion concentration profile may be obtained by using EPMA measurement of a cross section of the tempered glass sheet.

[0172] The Na ion mutual diffusion coefficient D_{Na} and K ion mutual diffusion coefficient D_K at 380° may each be calculated based on the ion concentration profile and the equation of [Math. 1] as described above, but may be obtained as follows: the tempered glass sheet having been subjected to ion exchange is subjected to heat treatment (annealing) at 380° C., and the diffusion coefficient is calculated from a difference in concentration before and after the heat treatment. A heat treatment time period is not particularly limited, but is 1 minute or more, 5 minutes or more, 10 minutes or more, or 20 minutes or more, particularly from 30 minutes to 120 minutes.

[0173] When two-step ion a exchange is performed, compressive stress value ($CS30_{2nd}$) at a depth of 30 μm after second ion exchange is lower than a compressive stress value ($CS30_{1st}$) at a depth of 30 μm after first ion exchange in some cases. A compressive stress drop rate (CS30Droprate) at a depth of 30 μm before and after the second ion exchange in such cases is represented by the following equation of [Math. 2]. A suitable upper limit range of the CS30Droprate is 1.00 or less, 0.70 or less, 0.50 or less, 0.45 or less, 0.40 or less, 0.35 or less, 0.32 or less, 0.30 or less, 0.28 or less, or 0.25 or less, particularly 0.20 or less. When the CS30Droprate is low, the $CS30_{2nd}$ is increased, and the strength of the tempered glass sheet is easily increased. Meanwhile, the lower limit thereof is not particularly limited, but is 0.05 or more or 0.10 or more, particularly 0.15 or more.

[Math. 2]

$$CS30_{Drop\ rate}=\frac{CS30_{2nd}-CS30_{1st}}{CS30_{1st}}$$

EXAMPLES

[0174] The present invention is described below by way of Examples. The following Examples are merely illustrative. The present invention is by no means limited to the following Examples.

EXAMPLE 1

[0175] The glass compositions and glass characteristics of Examples of the present invention (Samples Nos. 001 to 102 and Nos. 104 to 285) and Comparative Example (Sample No. 103) are shown in Tables 1 to 30. In each of the tables, the term "N.A." means not applicable, and the term "R_2O/Al_2O_3" means the molar ratio $([Li_2O]+[Na_2O]+[K_2O])/[Al_2O_3]$.

TABLE 1

Component (mol %)	No. 001	No. 002	No. 003	No. 004	No. 005	No. 006	No. 007	No. 008	No. 009	No. 010
SiO_2	69.867	69.863	69.862	69.866	69.859	69.854	69.962	65.864	65.862	65.865
Al_2O_3	10.0	10.0	10.0	10.0	10.0	10.0	10.0	12.0	12.0	12.0
B_2O_3	10.0	0.0	0.0	5.0	0.0	5.0	3.3	10.0	0.0	5.0
Li_2O	8.0	8.0	8.0	8.0	8.0	8.0	8.0	9.6	9.6	9.6
Na_2O	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.4	2.4	2.4
K_2O	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MgO	0.0	10.0	0.0	5.0	5.0	0.0	3.3	0.0	0.0	5.0
CaO	0.0	0.0	10.0	0.0	5.0	5.0	3.3	0.0	10.0	0.0
SrO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BaO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZnO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TiO_2	0.001	0.002	0.001	0.002	0.001	0.001	0.002	0.002	0.002	0.002
ZrO_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SnO_2	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Y_2O_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fe_2O_3	0.001	0.003	0.003	0.001	0.002	0.002	0.002	0.002	0.002	0.002
P_2O_5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SO_3	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000
Cl	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
MoO_3	0.001	0.002	0.004	0.001	0.007	0.012	0.004	0.002	0.004	0.001
$B_2O_3 + MgO + CaO$	10.0	10.0	10.0	10.0	10.0	10.0	9.9	10.0	10.0	10.0
$Al_2O_3 + Li_2O + Na_2O + K_2O$	20.0	20.0	20.0	20.0	20.0	20.0	20.0	24.0	24.0	24.0
R_2O/Al_2O_3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
$Al_2O_3/(R_2O + RO)$	1.00	0.50	0.50	0.67	0.50	0.67	0.60	1.00	0.55	0.71
Na_2O/Li_2O	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Li_2O/Al_2O_3	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Q	10.87	20.86	20.86	15.87	20.86	15.85	17.66	−2.94	7.06	2.07
X	473	503	533	488	518	503	503	601	661	616
Y	13	7	2	10	5	8	8	12	1	9
Z	59	39	37	49	38	48	46	69	47	59

TABLE 1-continued

Component (mol %)	No. 001	No. 002	No. 003	No. 004	No. 005	No. 006	No. 007	No. 008	No. 009	No. 010
W	415	474	355	444	414	385	415	506	446	535
U	8,331	8,533	8,532	8,432	8,532	8,431	8,463	8,239	8,441	8,340
ρ (g/cm^3)	2.280	2.419	2.472	2.354	2.445	2.393	2.397	2.304	2.493	2.378
Ts (° C.)	807	N.A.	792	816	N.A.	795	764	805	775	795
$\alpha_{300\text{-}380°\ C.}$ (×10^{-7}/° C.)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
$10^{2.5}$ dPa · s (° C.)	1,610	1,524	1,470	1,569	1,501	1,538	1,529	1,550	1,414	1,491
E (GPa)	67	84	85	77	N.A.	N.A.	N.A.	70	N.A.	79
CS_K (MPa)	503	915	N.A.	703	N.A.	N.A.	868	596	N.A.	N.A.
DOL_K (μm)	12	6	N.A.	8	N.A.	N.A.	5	12	N.A.	N.A.
CS_{Na} (MPa)	391	390	243	371	349	305	338	495	307	358
$CS30_{Na}$ (MPa)	116	120	46	106	74	65	91	163	58	83
DOC_{Na} (μm)	57	58	47	56	49	49	55	61	47	51
$CTcv_{Na}$ (MPa)	30	34	19	31	26	22	26	40	22	27
DOC_{Na}/DOL_K	4.8	9.6	N.A.	7.0	N.A.	N.A.	10.9	5.1	N.A.	N.A.
Acid resistance 5 wt % HCl 80° C. 24 h (mg/cm^2)	0.04	0.03	0.03	0.06	N.A.	N.A.	N.A.	0.32	0.01	0.05
Alkali resistance 5 wt % NaOH 80° C. 6 h (mg/cm^2)	1.20	0.30	0.30	0.70	N.A.	N.A.	N.A.	1.30	0.20	1.60
K1c (SEPB) (MPam$^{0.5}$)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Fracture energy γ	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

TABLE 2

Component (mol %)	No. 011	No. 012	No. 013	No. 014	No. 015	No. 016	No. 017	No. 018	No. 019	No. 020
SiO_2	65.866	65.866	65.966	73.864	73.864	73.856	73.866	73.866	73.859	73.955
Al_2O_3	12.0	12.0	12.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
B_2O_3	0.0	5.0	3.3	10.0	0.0	0.0	5.0	0.0	5.0	3.3
Li_2O	9.6	9.6	9.6	6.4	6.4	6.4	6.4	6.4	6.4	6.4
Na_2O	2.4	2.4	2.4	1.6	1.6	1.6	1.6	1.6	1.6	1.6
K_2O	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MgO	5.0	0.0	3.3	0.0	10.0	0.0	5.0	5.0	0.0	3.3
CaO	5.0	5.0	3.3	0.0	0.0	10.0	0.0	5.0	5.0	3.3
SrO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BaO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZnO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TiO_2	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
ZrO_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SnO_2	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Y_2O_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fe_2O_3	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
P_2O_5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SO_3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cl	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
MoO_3	0.000	0.000	0.000	0.002	0.002	0.010	0.000	0.000	0.007	0.011
B_2O_3 + MgO + CaO	10.0	10.0	9.9	10.0	10.0	10.0	10.0	10.0	10.0	9.9
$Al_2O_3 + Li_2O + Na_2O + K_2O$	24.0	24.0	24.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0
R_2O/Al_2O_3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
$Al_2O_3/(R_2O + RO)$	0.55	0.71	0.65	1.00	0.44	0.44	0.62	0.44	0.62	0.55
Na_2O/Li_2O	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Li_2O/Al_2O_3	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Q	7.07	2.07	3.87	24.66	34.66	34.66	29.67	34.67	29.66	31.46
X	646	631	631	345	375	405	360	390	375	375
Y	3	7	7	14	8	3	11	6	9	9
Z	48	58	55	50	30	28	40	29	39	36
W	505	476	506	325	383	265	354	324	295	325
U	8,441	8,340	8,372	8,423	8,624	8,624	8,524	8,624	8,523	8,554
ρ (g/cm^3)	2.469	2.414	2.420	2.256	2.390	2.446	2.328	2.420	2.369	2.373
Ts (° C.)	N.A.	756	N.A.	821	N.A.	817	837	N.A.	N.A.	N.A.
$\alpha_{300\text{-}380°\ C.}$ (×10^{-7}/° C.)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
$10^{2.5}$ dPa · s (° C.)	1,440	1,470	1,468	1,670	1,604	1,528	1,626	1,572	1,584	1,602
E (GPa)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
CS_K (MPa)	986	N.A.	N.A.	412	712	N.A.	573	N.A.	682	664
DOL_K (μm)	7	N.A.	N.A.	12	7	N.A.	9	N.A.	5	6
CS_{Na} (MPa)	554	417	459	275	276	202	262	261	226	261

TABLE 2-continued

Component (mol %)	No. 011	No. 012	No. 013	No. 014	No. 015	No. 016	No. 017	No. 018	No. 019	No. 020
$CS30_{Na}$ (MPa)	167	92	107	87	96	41	86	64	54	70
DOC_{Na} (μm)	58	51	52	60	62	48	60	52	52	54
$CTcv_{Na}$ (MPa)	44	27	32	20	27	15	23	20	17	21
DOC_{Na}/DOL_K	8.0	N.A.	N.A.	5.0	9.4	N.A.	6.7	N.A.	9.8	9.5
Acid resistance 5 wt % HCl 80° C. 24 h (mg/cm^2)	N.A.	N.A.	N.A.	0.03	0.00	0.00	N.A.	N.A.	N.A.	N.A.
Alkali resistance 5 wt % NaOH 80° C. 6 h (mg/cm^2)	N.A.	N.A.	N.A.	1.20	0.20	0.30	N.A.	N.A.	N.A.	N.A.
K1c (SEPB) ($MPam^{0.5}$)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Fracture energy γ	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

TABLE 3

Component (mol %)	No. 021	No. 022	No. 023	No. 024	No. 025	No. 026	No. 027	No. 028	No. 029	No. 030
SiO_2	73.866	73.866	73.855	73.854	73.854	73.863	73.862	69.863	69.865	69.865
Al_2O_3	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	9.0
B_2O_3	6.0	0.0	0.0	3.0	0.0	3.0	2.0	10.0	0.0	10.0
Li_2O	8.0	8.0	8.0	8.0	8.0	8.0	8.0	7.0	7.0	8.0
Na_2O	2.0	2.0	2.0	2.0	2.0	2.0	2.0	3.0	3.0	3.0
K_2O	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MgO	0.0	6.0	0.0	3.0	3.0	0.0	2.0	0.0	10.0	0.0
CaO	0.0	0.0	6.0	0.0	3.0	3.0	2.0	0.0	0.0	0.0
SrO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BaO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZnO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TiO_2	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
ZrO_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SnO_2	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Y_2O_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fe_2O_3	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
P_2O_5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SO_3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cl	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
MoO_3	0.000	0.000	0.011	0.012	0.012	0.003	0.004	0.003	0.001	0.001
B_2O_3 + MgO + CaO	6.0	6.0	6.0	6.0	6.0	6.0	6.0	10.0	10.0	10.0
Al_2O_3 + Li_2O + Na_2O + K_2O	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
R_2O/Al_2O_3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.22
$Al_2O_3/(R_2O + RO)$	1.00	0.63	0.63	0.77	0.63	0.77	0.71	1.00	0.50	0.82
Na_2O/Li_2O	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.43	0.43	0.38
Li_2O/Al_2O_3	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.70	0.70	0.89
Q	18.87	24.87	24.86	21.85	24.85	21.86	22.86	11.36	21.37	12.37
X	480	498	516	489	507	498	498	400	430	422
Y	16	12	9	14	10	12	12	14	8	14
Z	61	49	47	55	48	54	52	49	29	52
W	433	468	397	451	433	415	433	345	403	368
U	8,306	8,427	8,426	8,366	8,426	8,367	8,387	8.306	8,508	8,080
ρ (g/cm^3)	2.299	2.377	2.414	2.341	2.397	2.366	2.368	2.282	2.420	2.296
Ts (° C.)	861	N.A.	N.A.	869	N.A.	N.A.	N.A.	819	N.A.	745
$\alpha_{300\text{-}380°\ C.}$ ($\times 10^{-7}$/° C.)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
$10^{2.5}$ dPa · s (° C.)	1,677	1,633	1,593	1,641	1,623	1,623	1,630	1,616	1,541	1,623
E (GPa)	71	81	N.A.	77	N.A.	N.A.	N.A.	67	84	70
CS_K (MPa)	638	867	854	779	884	733	790	553	1,026	552
DOL_K (μm)	15	9	5	11	7	8	8	12	6	10
CS_{Na} (MPa)	N.A.	359	342	N.A.	396	344	389	312	312	241
$CS30_{Na}$ (MPa)	N.A.	165	101	N.A.	132	120	132	121	108	102
DOC_{Na} (μm)	N.A.	75	57	N.A.	61	62	61	67	60	70
$CTcv_{Na}$ (MPa)	N.A.	44	27	N.A.	36	31	34	28	34	27
DOC_{Na}/DOL_K	N.A.	8.0	10.9	N.A.	8.6	8.3	7.3	5.6	9.4	7.1
Acid resistance 5 wt % HCl 80° C. 24 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Alkali resistance 5 wt % NaOH 80° C. 6 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

TABLE 3-continued

Component (mol %)	No. 021	No. 022	No. 023	No. 024	No. 025	No. 026	No. 027	No. 028	No. 029	No. 030
K1c (SEPB) ($MPam^{0.5}$)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Fracture energy γ	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

TABLE 4

Component (mol %)	No. 031	No. 032	No. 033	No. 034	No. 035	No. 036	No. 037	No. 038	No. 039	No. 040
SiO_2	69.865	69.863	69.865	69.865	69.865	69.866	69.866	69.865	69.864	73.854
Al_2O_3	9.0	11.0	11.0	9.0	9.0	10.0	9.0	11.0	9.0	10.0
B_2O_3	0.0	10.0	0.0	10.0	0.0	5.0	5.0	5.0	5.0	6.0
Li_2O	8.0	7.0	7.0	9.0	9.0	7.0	8.0	7.0	9.0	7.0
Na_2O	3.0	2.0	2.0	2.0	2.0	3.0	3.0	2.0	2.0	3.0
K_2O	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MgO	10.0	0.0	10.0	0.0	10.0	5.0	5.0	5.0	5.0	0.0
CaO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SrO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BaO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZnO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TiO_2	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
ZrO_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SnO_2	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Y_2O_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fe_2O_3	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
P_2O_5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SO_3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cl	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
MoO_3	0.001	0.003	0.001	0.001	0.001	0.000	0.000	0.001	0.002	0.012
B_2O_3 + MgO + CaO	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	6.0
Al_2O_3 + Li_2O + Na_2O + K_2O	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
R_2O/Al_2O_3	1.22	0.82	0.82	1.22	1.22	1.00	1.22	0.82	1.22	1.00
$Al_2O_3/(R_2O + RO)$	0.43	1.22	0.58	0.82	0.43	0.67	0.56	0.79	0.56	1.00
Na_2O/Li_2O	0.38	0.29	0.29	0.22	0.22	0.43	0.38	0.29	0.22	0.43
Li_2O/Al_2O_3	0.89	0.64	0.64	1.00	1.00	0.70	0.89	0.64	1.00	0.70
Q	22.37	9.86	19.87	11.87	21.87	16.37	17.37	14.87	16.86	19.35
X	451	452	481	495	524	415	437	466	510	407
Y	7	14	8	13	6	11	10	11	9	17
Z	32	57	37	62	42	39	42	47	52	50
W	426	392	450	438	497	374	397	421	468	362
U	8,281	8,557	8,759	8,105	8,306	8,407	8,181	8,658	8,206	8,280
ρ (g/cm^3)	2.419	2.283	2.421	2.293	2.415	2.356	2.359	2.351	2.356	2.295
Ts (° C.)	N.A.	856	N.A.	742	N.A.	817	773	857	N.A.	869
$\alpha_{300\text{-}380°\ C.}$ ($\times 10^{-7}$/° C.)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
$10^{2.5}$ dPa · s (° C.)	1,511	1,608	1,546	1,595	1,500	1,563	1,533	1,589	1,530	1,680
E (GPa)	84	68	86	70	85	77	78	77	78	70
CS_K (MPa)	952	565	N.A.	543	964	773	756	759	721	637
DOL_K (μm)	6	10	N.A.	9	5	9	8	8	7	16
CS_{Na} (MPa)	368	312	336	339	387	310	298	330	379	288
$CS30_{Na}$ (MPa)	115	113	107	117	149	112	97	115	115	151
DOC_{Na} (μm)	58	64	59	62	67	63	59	62	58	84
$CTcv_{Na}$ (MPa)	33	27	31	29	35	30	29	29	30	42
DOC_{Na}/DOL_K	9.2	6.4	N.A.	7.0	12.6	7.1	7.6	8.0	8.4	5.2
Acid resistance 5 wt % HCl 80° C. 24 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Alkali resistance 5 wt % NaOH 80° C. 6 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
K1c (SEPB) ($MPam^{0.5}$)	N.A.	0.86	0.87	N.A.	N.A.	N.A.	N.A.	0.92	0.75	N.A.
Fracture energy γ	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

TABLE 5

Component (mol %)	No. 041	No. 042	No. 043	No. 044	No. 045	No. 046	No. 047	No. 048	No. 049	No. 050
SiO_2	73.858	73.866	73.858	73.862	73.862	73.855	73.858	65.865	65.864	65.865
Al_2O_3	9.0	11.0	9.0	10.0	9.0	11.0	9.0	12.0	10.8	13.2
B_2O_3	6.0	6.0	6.0	3.0	3.0	3.0	3.0	10.0	10.0	10.0
Li_2O	8.0	7.0	9.0	7.0	8.0	7.0	9.0	8.4	9.6	8.4
Na_2O	3.0	2.0	2.0	3.0	3.0	2.0	2.0	3.6	3.6	2.4
K_2O	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MgO	0.0	0.0	0.0	3.0	3.0	3.0	3.0	0.0	0.0	0.0
CaO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SrO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BaO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZnO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TiO_2	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
ZrO_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SnO_2	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Y_2O_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fe_2O_3	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
P_2O_5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SO_3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cl	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
MoO_3	0.008	0.000	0.008	0.004	0.004	0.011	0.008	0.001	0.002	0.001
B_2O_3 + MgO + CaO	6.0	6.0	6.0	6.0	6.0	6.0	6.0	10.0	10.0	10.0
Al_2O_3 + Li_2O + Na_2O + K_2O	20.0	20.0	20.0	20.0	20.0	20.0	20.0	24.0	24.0	24.0
R_2O/Al_2O_3	1.22	0.82	1.22	1.00	1.22	0.82	1.22	1.00	1.22	0.82
$Al_2O_3/(R_2O + RO)$	0.82	1.22	0.82	0.77	0.64	0.92	0.64	1.00	0.82	1.22
Na_2O/Li_2O	0.38	0.29	0.22	0.43	0.38	0.29	0.22	0.43	0.38	0.29
Li_2O/Al_2O_3	0.89	0.64	1.00	0.70	0.89	0.64	1.00	0.70	0.89	0.64
Q	20.36	17.87	19.86	22.36	23.36	20.86	22.86	−2.33	−1.14	−4.14
X	429	459	502	416	438	468	511	514	540	575
Y	16	16	15	15	14	14	13	14	13	13
Z	53	58	63	44	47	52	57	57	60	66
W	386	410	456	380	403	427	474	421	449	478
U	8,054	8,533	8,079	8,342	8,115	8,592	8,140	8,210	7,938	8,511
ρ (g/cm^3)	2.319	2.288	2.313	2.343	2.348	2.337	2.344	2.307	2.319	2.310
Ts (° C.)	772	927	775	878	N.A.	923	N.A.	811	741	840
$\alpha_{300\text{-}380°\ C.}$ (×10^{-7}/° C.)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
$10^{2.5}$ dPa · s (° C.)	1,655	1,682	1,637	1,659	1,623	1,673	1,617	1,569	1,548	1,554
E (GPa)	74	71	74	76	77	77	77	69	72	70
CS_K (MPa)	597	645	573	778	719	794	711	676	639	693
DOL_K (μm)	11	14	10	12	12	11	9	12	10	9
CS_{Na} (MPa)	308	306	366	300	316	255	349	375	362	384
$CS30_{Na}$ (MPa)	138	151	152	141	138	121	146	171	147	150
DOC_{Na} (μm)	75	80	71	75	72	75	69	75	68	68
$CTcv_{Na}$ (MPa)	32	39	35	39	35	38	39	42	38	33
DOC_{Na}/DOL_K	6.8	5.7	7.2	6.1	6.1	6.7	7.7	6.1	6.8	7.3
Acid resistance 5 wt % HCl 80° C. 24 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Alkali resistance 5 wt % NaOH 80° C. 6 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
K1c (SEPB) (MPam$^{0.5}$)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Fracture energy γ	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

TABLE 6

Component (mol %)	No. 051	No. 052	No. 053	No. 054	No. 055	No. 056	No. 057	No. 058	No. 059	No. 060
SiO_2	65.865	65.865	65.863	65.864	65.863	69.864	69.863	69.864	69.864	69.864
Al_2O_3	10.8	12.0	10.8	13.2	10.8	10.0	10.0	10.5	10.0	11.0
B_2O_3	10.0	5.0	5.0	5.0	5.0	7.5	7.5	7.5	7.5	7.5
Li_2O	10.8	8.4	9.6	8.4	10.8	8.0	8.5	8.0	7.0	7.0
Na_2O	2.4	3.6	3.6	2.4	2.4	2.0	1.5	1.5	3.0	2.0
K_2O	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MgO	0.0	5.0	5.0	5.0	5.0	2.5	2.5	2.5	2.5	2.5
CaO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SrO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BaO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZnO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TABLE 6-continued

Component (mol %)	No. 051	No. 052	No. 053	No. 054	No. 055	No. 056	No. 057	No. 058	No. 059	No. 060
TiO_2	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
ZrO_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SnO_2	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Y_2O_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fe_2O_3	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
P_2O_5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SO_3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cl	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
MoO_3	0.001	0.001	0.003	0.002	0.003	0.002	0.003	0.002	0.002	0.002
B_2O_3 + MgO + CaO	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Al_2O_3 + Li_2O + Na_2O + K_2O	24.0	24.0	24.0	24.0	24.0	20.0	20.0	20.0	20.0	20.0
R_2O/Al_2O_3	1.22	1.00	1.22	0.82	1.22	1.00	1.00	0.90	1.00	0.82
$Al_2O_3/(R_2O + RO)$	0.82	0.71	0.59	0.84	0.59	0.80	0.80	0.88	0.80	0.96
Na_2O/Li_2O	0.22	0.43	0.38	0.29	0.22	0.25	0.18	0.19	0.43	0.29
Li_2O/Al_2O_3	1.00	0.70	0.89	0.64	1.00	0.80	0.85	0.76	0.70	0.64
Q	−1.74	2.67	3.86	0.86	3.26	13.36	13.11	12.61	13.86	12.36
X	627	528	554	590	642	481	517	506	408	459
Y	11	10	9	10	8	12	11	12	13	13
Z	72	47	50	56	62	54	60	58	44	52
W	534	450	478	507	563	430	465	454	359	407
U	7,968	8,310	8,039	8,612	8,069	8,381	8,394	8,507	8,357	8,608
ρ (g/cm^3)	2.315	2.380	2.384	2.377	2.380	2.317	2.316	2.314	2.321	2.316
Ts (° C.)	744	802	N.A.	843	746	811	810	837	812	856
$\alpha_{300\text{-}380°\ C.}$ (×10^{-7}/° C.)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
$10^{2.5}$ dPa · s (° C.)	1,533	1,508	1,481	1,515	1,473	1,587	1,584	1,591	1,600	1,599
E (GPa)	72	79	79	79	80	73	73	72	72	72
CS_K (MPa)	627	964	867	952	850	692	674	689	665	673
DOL_K (μm)	9	8	7	7	6	9	8	9	10	10
CS_{Na} (MPa)	420	419	405	449	501	375	402	390	309	323
$CS30_{Na}$ (MPa)	133	153	137	136	143	124	124	128	115	122
DOC_{Na} (μm)	59	64	61	58	56	61	59	61	65	66
$CTcv_{Na}$ (MPa)	37	37	36	36	40	31	30	32	28	29
DOC_{Na}/DOL_K	6.6	8.1	8.7	8.7	9.0	6.7	7.0	6.9	6.5	6.9
Acid resistance 5 wt % HCl 80° C. 24 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Alkali resistance 5 wt % NaOH 80° C. 6 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
K1c (SEPB) (MPam$^{0.5}$)	N.A.	N.A.	N.A.	N.A.	0.85	N.A.	N.A.	N.A.	N.A.	N.A.
Fracture energy γ	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

TABLE 7

Component (mol %)	No. 061	No. 062	No. 063	No. 064	No. 065	No. 066	No. 067	No. 068	No. 069	No. 070
SiO_2	71.864	71.864	71.863	71.864	71.864	69.864	69.864	67.864	67.966	67.865
Al_2O_3	10.0	10.0	10.5	10.0	11.0	10.0	10.5	11.0	11.0	11.0
B_2O_3	8.0	8.0	8.0	8.0	8.0	10.0	10.0	7.5	7.5	7.5
Li_2O	8.0	8.5	8.0	7.0	7.0	8.5	8.0	8.8	9.3	7.7
Na_2O	2.0	1.5	1.5	3.0	2.0	1.5	1.5	2.2	1.6	3.3
K_2O	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MgO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	2.5	2.5
CaO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SrO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BaO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZnO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TiO_2	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
ZrO_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SnO_2	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Y_2O_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fe_2O_3	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
P_2O_5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SO_3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cl	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
MoO_3	0.002	0.002	0.003	0.002	0.002	0.002	0.002	0.002	0.000	0.001
B_2O_3 + MgO + CaO	8.0	8.0	8.0	8.0	8.0	10.0	10.0	10.0	10.0	10.0
Al_2O_3 + Li_2O + Na_2O + K_2O	20.0	20.0	20.0	20.0	20.0	20.0	20.0	22.0	21.9	22.0

TABLE 7-continued

Component (mol %)	No. 061	No. 062	No. 063	No. 064	No. 065	No. 066	No. 067	No. 068	No. 069	No. 070
R_2O/Al_2O_3	1.00	1.00	0.90	1.00	0.82	1.00	0.90	1.00	0.99	1.00
$Al_2O_3/(R_2O + RO)$	1.00	1.00	1.11	1.00	1.22	1.00	1.11	0.81	0.82	0.81
Na_2O/Li_2O	0.25	0.18	0.19	0.43	0.29	0.18	0.19	0.25	0.17	0.43
Li_2O/Al_2O_3	0.80	0.85	0.76	0.70	0.64	0.85	0.76	0.80	0.85	0.70
Q	14.86	14.61	14.11	15.36	13.86	10.61	10.11	6.46	6.47	7.02
X	477	513	502	404	455	510	499	545	583	464
Y	14	14	14	15	15	13	13	11	11	12
Z	60	65	64	50	57	65	63	59	65	48
W	424	460	448	353	401	451	439	475	513	397
U	8,319	8,331	8,444	8,294	8,545	8,344	8,457	8,336	8,364	8,308
ρ (g/cm^3)	2.286	2.284	2.285	2.289	2.290	2.275	2.277	2.329	2.328	2.333
Ts (° C.)	844	850	875	851	890	823	846	806	806	806
$\alpha_{300\text{-}380°\ C.}$ ($\times 10^{-7}$/° C.)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
$10^{2.5}$ dPa · s (° C.)	1,651	1,658	1,658	1,660	1,656	1,618	1,612	1,558	1,554	1,567
E (GPa)	69	69	68	68	69	67	67	73	74	73
CS_K (MPa)	589	590	599	592	602	544	570	748	738	753
DOL_K (μm)	13	13	13	15	12	11	11	9	8	10
CS_{Na} (MPa)	371	404	385	310	328	372	363	409	465	344
$CS30_{Na}$ (MPa)	162	168	152	143	135	135	134	132	142	128
DOC_{Na} (μm)	73	70	68	76	69	64	65	60	58	65
$CTcv_{Na}$ (MPa)	39	40	37	36	32	35	32	35	37	32
DOC_{Na}/DOL_K	5.5	5.5	5.4	5.2	5.7	5.6	5.9	6.9	7.1	6.6
Acid resistance 5 wt % HCl 80° C. 24 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Alkali resistance 5 wt % NaOH 80° C. 6 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
K1c (SEPB) (MPam$^{0.5}$)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Fracture energy γ	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

TABLE 8

Component (mol %)	No. 071	No. 072	No. 073	No. 074	No. 075	No. 076	No. 077	No. 078	No. 079	No. 080
SiO_2	67.865	69.865	69.963	69.863	69.864	65.863	66.965	67.965	67.965	73.865
Al_2O_3	12.1	11.0	11.0	11.0	12.1	10.8	12.6	11.0	11.5	9.0
B_2O_3	7.5	6.0	6.0	6.0	6.0	5.0	7.5	7.5	7.5	3.0
Li_2O	7.7	8.8	9.3	7.7	7.7	8.4	8.0	8.2	8.2	7.0
Na_2O	2.2	2.2	1.6	3.3	2.2	4.8	2.3	2.7	2.2	4.0
K_2O	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MgO	2.5	2.0	2.0	2.0	2.0	5.0	2.5	2.5	2.5	3.0
CaO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SrO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BaO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZnO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TiO_2	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
ZrO_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SnO_2	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Y_2O_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fe_2O_3	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
P_2O_5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SO_3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cl	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
MoO_3	0.001	0.001	0.003	0.003	0.002	0.003	0.001	0.001	0.001	0.001
B_2O_3 + MgO + CaO	10.0	8.0	8.0	8.0	8.0	10.0	10.0	10.0	10.0	6.0
$Al_2O_3 + Li_2O + Na_2O + K_2O$	22.0	22.0	21.9	22.0	22.0	24.0	22.9	21.9	21.9	20.0
R_2O/Al_2O_3	0.82	1.00	0.99	1.00	0.82	1.22	0.82	0.99	0.90	1.22
$Al_2O_3/(R_2O + RO)$	0.98	0.85	0.85	0.85	1.02	0.59	0.98	0.82	0.89	0.64
Na_2O/Li_2O	0.29	0.25	0.17	0.43	0.29	0.57	0.29	0.33	0.27	0.57
Li_2O/Al_2O_3	0.64	0.80	0.85	0.70	0.64	0.78	0.63	0.75	0.71	0.78
Q	5.37	9.97	9.96	10.51	8.86	4.46	2.22	7.02	6.27	23.87
X	521	547	585	466	523	467	548	503	529	365
Y	12	13	12	14	14	11	12	12	12	15
Z	57	61	67	49	58	37	59	54	58	36
W	450	481	520	403	456	393	468	436	459	333
U	8,585	8,313	8,341	8,286	8,562	8,009	8,575	8,337	8,462	8,091
ρ (g/cm^3)	2.329	2.329	2.328	2.333	2.330	2.386	2.334	2.330	2.328	2.351

TABLE 8-continued

Component (mol %)	No. 071	No. 072	No. 073	No. 074	No. 075	No. 076	No. 077	No. 078	No. 079	No. 080
Ts (° C.)	850	827	828	827	877	759	839	808	829.5	818
$\alpha_{300\text{-}380^\circ C.}$ ($\times 10^{-7}$/° C.)	48.1	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
$10^{2.5}$ dPa · s (° C.)	1,576	1,588	1,588	1,605	1,608	1,472	1,538	1,549	1,553	1,633
E (GPa)	73	74	75	74	74	79	74	74	73	78
CS_K (MPa)	761	770	756	768	781	871	790	747	743	726
DOL_K (μm)	9	10	9	11	10	8	8	10	9	12
CS_{Na} (MPa)	376	432	442	346	374	322	376	342	385	261
$CS30_{Na}$ (MPa)	124	168	168	147	141	135	141	150	141	129
DOC_{Na} (μm)	60	67	66	71	65	70	65	73	64	80
$CTcv_{Na}$ (MPa)	32	41	40	37	37	36	36	37	37	35
DOC_{Na}/DOL_K	6.9	6.8	7.1	6.3	6.5	8.7	7.7	7.5	7.0	6.9
Acid resistance 5 wt % HCl 80° C. 24 h (mg/cm^2)	0.03	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Alkali resistance 5 wt % NaOH 80° C. 6 h (mg/cm^2)	1.32	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
K1c (SEPB) (MPam$^{0.5}$)	0.83	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Fracture energy γ	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

TABLE 9

Component (mol %)	No. 081	No. 082	No. 083	No. 084	No. 085	No. 086	No. 087	No. 088	No. 089	No. 090
SiO_2	69.864	69.858	69.866	69.861	69.858	69.860	69.862	69.859	69.854	69.859
Al_2O_3	10.8	10.8	10.8	10.8	10.8	10.8	10.8	11.8	12.8	12.8
B_2O_3	3.0	2.0	1.0	0.0	1.0	1.0	0.0	1.0	1.0	0.0
Li_2O	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4
Na_2O	4.8	5.8	6.8	7.8	5.8	4.8	5.8	5.8	4.8	5.8
K_2O	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MgO	3.0	3.0	3.0	3.0	4.0	5.0	5.0	3.0	3.0	3.0
CaO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SrO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BaO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZnO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TiO_2	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
ZrO_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SnO_2	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Y_2O_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fe_2O_3	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
P_2O_5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SO_3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cl	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
MoO_3	0.002	0.008	0.000	0.005	0.008	0.006	0.004	0.007	0.012	0.007
$B_2O_3 + MgO + CaO$	6.0	5.0	4.0	3.0	5.0	6.0	5.0	4.0	4.0	3.0
$Al_2O_3 + Li_2O + Na_2O + K_2O$	24.0	25.0	26.0	27.0	25.0	24.0	25.0	26.0	26.0	27.0
R_2O/Al_2O_3	1.22	1.31	1.41	1.50	1.31	1.22	1.31	1.20	1.03	1.11
$Al_2O_3/(R_2O + RO)$	0.67	0.63	0.59	0.56	0.59	0.59	0.56	0.69	0.79	0.74
Na_2O/Li_2O	0.57	0.69	0.81	0.93	0.69	0.57	0.69	0.69	0.57	0.69
Li_2O/Al_2O_3	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.71	0.66	0.66
Q	10.46	9.96	9.47	8.96	10.96	12.46	11.96	7.96	6.45	5.96
X	468	447	426	405	450	474	453	477	528	507
Y	14	15	16	16	14	13	14	15	15	16
Z	42	37	32	26	35	38	33	39	47	42
W	400	375	350	325	380	411	386	397	445	420
U	7,944	7,778	7,614	7,449	7,798	7,984	7,819	7,865	8,116	7,951
ρ (g/cm^3)	2.376	2.389	2.400	2.410	2.398	2.397	2.408	2.392	2.388	2.400
Ts (° C.)	795	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
$\alpha_{300\text{-}380^\circ C.}$ ($\times 10^{-7}$/° C.)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
$10^{2.5}$ dPa · s (° C.)	1,564	1,549	1,544	1,536	1,546	1,547	1,546	1,579	1,596	1,602
E (GPa)	77	79	80	80	80	81	81	79	80	80
CS_K (MPa)	824	817	808	803	876	944	955	922	1,050	1,093
DOL_K (μm)	11	11	12	13	11	10	11	13	14	14
CS_{Na} (MPa)	302	282	258	253	323	310	293	282	334	291
$CS30_{Na}$ (MPa)	152	149	148	150	157	163	162	163	189	188
DOC_{Na} (μm)	80	83	91	96	79	83	87	92	90	110
$CTcv_{Na}$ (MPa)	43	46	48	47	46	49	52	53	58	71

TABLE 9-continued

Component (mol %)	No. 081	No. 082	No. 083	No. 084	No. 085	No. 086	No. 087	No. 088	No. 089	No. 090
DOC_{Na}/DOL_K	7.5	7.4	7.6	7.1	7.0	8.1	7.6	7.1	6.7	8.0
Acid resistance 5 wt % HCl 80° C. 24 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Alkali resistance 5 wt % NaOH 80° C. 6 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
K1c (SEPB) ($MPam^{0.5}$)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Fracture energy γ	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

TABLE 10

Component (mol %)	No. 091	No. 092	No. 093	No. 094	No. 095	No. 096	No. 097	No. 098	No. 099	No. 100
SiO_2	70.858	71.866	71.866	65.864	66.365	66.064	67.644	69.365	66.56	66.564
Al_2O_3	10.8	10.8	10.8	12.1	12.1	12.1	12.1	11.9	12.1	12.1
B_2O_3	1.0	1.0	0.0	7.5	7.0	7.5	7.5	4.3	7.5	7.5
Li_2O	8.4	8.4	8.4	8.2	8.2	7.7	7.7	7.7	7.7	7.7
Na_2O	5.8	4.8	5.8	3.4	3.4	3.7	2.2	3.8	2.9	3.2
K_2O	0.0	0.0	0.0	0.3	0.3	0.3	0	0.3	0.6	0.3
MgO	3.0	3.0	3.0	2.5	2.5	2.5	2.5	2.5	2.5	2.5
CaO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SrO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BaO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZnO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TiO_2	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
ZrO_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SnO_2	0.03	0.03	0.03	0.03	0.03	0.03	0.25	0.03	0.03	0.03
Y_2O_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fe_2O_3	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
P_2O_5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SO_3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cl	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
MoO_3	0.008	0.000	0.000	0.002	0.001	0.002	0.002	0.001	0.002	0.002
$B_2O_3 + MgO + CaO$	4.0	4.0	3.0	10.0	9.5	10.0	10.0	6.8	10.0	10.0
$Al_2O_3 + Li_2O + Na_2O + K_2O$	25.0	24.0	25.0	24.0	24.0	23.8	22.0	23.7	23.3	23.3
R_2O/Al_2O_3	1.31	1.22	1.31	0.98	0.98	0.97	0.82	0.99	0.93	0.93
$Al_2O_3/(R_2O + RO)$	0.63	0.67	0.63	0.84	0.84	0.85	0.98	0.83	0.88	0.88
Na_2O/Li_2O	0.69	0.57	0.69	0.41	0.41	0.48	0.29	0.49	0.38	0.42
Li_2O/Al_2O_3	0.78	0.78	0.78	0.68	0.68	0.64	0.64	0.65	0.64	0.64
Q	11.96	14.47	13.97	0.26	1.27	1.01	5.14	7.97	2.41	2.26
X	449	471	450	519	520	487	521	485	506	498
Y	15	15	16	12	12	12	12	14	12	12
Z	37	43	37	52	52	48	57	48	53	51
W	379	409	384	435	437	406	450	413	429	420
U	7,772	7,931	7,767	8,284	8,281	8,303	8,565	8,249	8,386	8,382
ρ (g/cm^3)	2.390	2.380	2.391	2.345	2.347	2.343	2.338	2.357	2.338	2.337
Ts (° C.)	N.A.	N.A.	N.A.	795	799	801	850	896	806	805
$\alpha_{300\text{-}380°\ C.}$ ($\times 10^{-7}$/° C.)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
$10^{2.5}$ dPa · s (° C.)	1,575	1,600	1,597	1,526	1,538	1,529	1,559	1,604	1,532	1,531
E (GPa)	79	79	N.A.	N.A.	N.A.	73	N.A.	N.A.	73	74
CS_K (MPa)	853	881	878	794	801	783	766	882	744	756
DOL_K (μm)	12	12	13	10	10	11	9	13	10	10
CS_{Na} (MPa)	244	289	254	380	366	340	355	321	339	354
$CS30_{Na}$ (MPa)	152	163	155	139	123	122	128	162	110	130
DOC_{Na} (μm)	103	88	97	65	61	63	64	82	60	65
$CTcv_{Na}$ (MPa)	51	57	57	33	34	32	32	41	30	32
DOC_{Na}/DOL_K	8.8	7.5	7.5	6.4	5.9	5.9	7.3	6.5	5.7	6.6
Acid resistance 5 wt % HCl 80° C. 24 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.	0.17	N.A.	0.03	0.20	0.27
Alkali resistance 5 wt % NaOH 80° C. 6 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.	1.32	N.A.	0.88	N.A.	N.A.
K1c (SEPB) ($MPam^{0.5}$)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Fracture energy γ	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

TABLE 11

Component (mol %)	No. 101	No. 102	No. 103
SiO_2	66.565	66.564	68.146
Al_2O_3	12.1	12.1	9.5
B_2O_3	7.5	7.2	0.1
Li_2O	7.7	7.7	9.0
Na_2O	2.9	2.9	8.2
K_2O	0.9	0.9	3.0
MgO	2.2	2.5	2.0
CaO	0.0	0.0	0.0
SrO	0.0	0.0	0.0
BaO	0.0	0.0	0.0
ZnO	0.0	0.0	0.0
TiO_2	0.002	0.002	0.002
ZrO_2	0.0	0.0	0.0
SnO_2	0.03	0.03	0.04
Y_2O_3	0.0	0.0	0.0
Fe_2O_3	0.002	0.002	0.002
P_2O_5	0.0	0.0	0.0
SO_3	0.000	0.000	0.000
Cl	0.10	0.10	0.01
MoO_3	0.001	0.002	0.000
B_2O_3 + MgO + CaO	9.7	9.7	2.1
$Al_2O_3 + Li_2O + Na_2O + K_2O$	23.6	23.6	29.7
R_2O/Al_2O_3	0.95	0.95	2.13
$Al_2O_3/(R_2O + RO)$	0.88	0.86	0.43
Na_2O/Li_2O	0.38	0.38	0.91
Li_2O/Al_2O_3	0.64	0.64	0.95
Q	2.12	2.41	6.25
X	506	507	392

TABLE 11-continued

Component (mol %)	No. 101	No. 102	No. 103
Y	12	12	16
Z	53	53	26
W	429	430	312
U	8,334	8,340	6,729
ρ (g/cm^3)	2.337	2.342	2.428
Ts (° C.)	799	800	701
$\alpha_{300\text{-}380^\circ C.}$ ($\times 10^{-7}$/° C.)	N.A.	N.A.	94.3
$10^{2.5}$ dPa's (° C.)	1,538	1,532	1,427
E (GPa)	N.A.	N.A.	78
CS_K (MPa)	722	736	506
DOL_K (μm)	11	11	17
CS_{Na} (MPa)	333	331	136
$CS30_{Na}$ (MPa)	102	118	N.A.
DOC_{Na} (μm)	58	64	79
$CTcv_{Na}$ (MPa)	27	28	N.A.
DOC_{Na}/DOL_K	5.2	5.6	4.6
Acid resistance 5 wt % HCl 80° C. 24 h (mg/cm^2)	0.18	0.22	0.00
Alkali resistance 5 wt % NaOH 80° C. 6 h (mg/cm^2)	N.A.	N.A.	0.56
K1c (SEPB) (MPam$^{0.5}$)	N.A.	N.A.	N.A.
Fracture energy γ	N.A.	N.A.	N.A.

TABLE 12

Component (mol %)	No. 104	No. 105	No. 106	No. 107	No. 108	No. 109	No. 110	No. 111	No. 112	No. 113
SiO_2	67.145	66.845	66.845	67.125	67.095	67.075	66.885	67.275	67.365	66.825
Al_2O_3	16.0	15.8	15.6	16.0	16.0	16.0	14.4	15.2	16.0	15.6
B_2O_3	1.2	1.5	1.7	1.2	1.2	1.2	3.6	2.3	1.1	1.7
Li_2O	7.5	7.5	7.5	7.5	7.5	7.5	3.8	5.7	7.4	7.5
Na_2O	7.4	7.5	7.5	7.4	7.4	7.4	3.7	5.5	7.2	7.5
K_2O	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.3	0.3
MgO	0.3	0.4	0.4	0.3	0.3	0.3	2.2	1.2	0.4	0.4
CaO	0.0	0.0	0.0	0.0	0.0	0.0	3.7	1.8	0.1	0.0
SrO	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.1	0.0	0.0
BaO	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.6	0.0	0.0
ZnO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TiO_2	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
ZrO_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SnO_2	0.05	0.05	0.05	0.07	0.10	0.12	0.06	0.04	0.03	0.07
Y_2O_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fe_2O_3	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
P_2O_5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SO_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cl	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
MoO_3	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
B_2O_3 + MgO + CaO	1.5	1.9	2.1	1.5	1.5	1.5	9.5	5.3	1.6	2.1
$Al_2O_3 + Li_2O + Na_2O + K_2O$	31.2	31.1	30.9	31.2	31.2	31.2	22.1	26.6	30.9	30.9
R_2O/Al_2O_3	0.95	0.97	0.98	0.95	0.95	0.95	0.53	0.75	0.93	0.98
$Al_2O_3/(R_2O + RO)$	1.03	1.01	0.99	1.03	1.03	1.03	0.96	1.01	1.04	0.99
Na_2O/Li_2O	0.99	1.00	1.00	0.99	0.99	0.99	0.97	0.96	0.97	1.00
Li_2O/Al_2O_3	0.47	0.47	0.48	0.47	0.47	0.47	0.26	0.38	0.46	0.48
Q	−8.45	−8.60	−8.20	−8.47	−8.50	−8.53	6.73	−0.47	−7.63	−8.22
X	512	504	498	512	512	512	381	450	512	498
Y	20	19	19	20	20	20	11	16	19	19
Z	42	40	40	42	42	41	27	35	42	40
W	384	377	372	384	384	384	264	329	386	372
U	8,006	7,976	7,959	8,004	8,002	8,000	9,156	8,587	8,057	7,957
ρ (g/cm^3)	2.397	2.397	2.395	2.398	2.400	2.400	2.462	2.430	2.398	2.395
Ts (° C.)	935	922	915	937	935	935	906	913	938	912
$\alpha_{300\text{-}380^\circ C.}$ ($\times 10^{-7}$/° C.)	N.A.	N.A.	77	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
$10^{2.5}$ dPa · s (° C.)	1,627	1,615	1,611	1,626	1,624	1,626	1,569	1,600	1,628	1,614
E (GPa)	78	78	78	79	78	78	80	78	78	77
CS_K (MPa)	1,237	1,212	1,195	1,251	1,249	1,256	791	1,252	1,279	1,184

TABLE 12-continued

Component (mol %)	No. 104	No. 105	No. 106	No. 107	No. 108	No. 109	No. 110	No. 111	No. 112	No. 113
DOL_K (μm)	25	24	24	25	25	25	N.A.	11	24	24
CS_{Na} (MPa)	299	322	333	317	328	324	199	319	338	306
$CS30_{Na}$ (MPa)	196	202	206	203	210	205	56	133	205	190
DOC_{Na} (μm)	111	103	102	106	107	104	56	70	99	101
$CTcv_{Na}$ (MPa)	70	68	65	68	69	67	15	35	65	65
DOC_{Na}/DOL_K	4.5	4.2	4.2	4.3	4.3	4.2	N.A.	6.1	4.2	4.3
Acid resistance 5 wt % HCl 80° C. 24 h (mg/cm^2)	0.16	0.24	0.22	0.20	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Alkali resistance 5 wt % NaOH 80° C. 6 h (mg/cm^2)	0.50	0.52	0.50	0.49	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
K1c (SEPB) ($MPam^{0.5}$)	0.81	N.A.	0.80	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Fracture energy γ	8.39	N.A.	8.23	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

TABLE 13

Component (mol %)	No. 114	No. 115	No. 116	No. 117	No. 118	No. 119	No. 120	No. 121	No. 122	No. 123
SiO_2	66.795	59.065	61.065	63.165	62.665	65.765	74.465	63.165	70.165	67.665
Al_2O_3	15.6	17.2	14.4	13.2	13.2	16.0	9.9	17.8	10.8	11.4
B_2O_3	1.7	2.2	10.0	10.0	10.0	3.0	6.5	0.2	9.3	5.8
Li_2O	7.5	12.3	10.1	8.2	8.4	7.5	6.6	8.7	8.0	11.9
Na_2O	7.5	6.3	4.3	4.8	5.1	7.3	2.1	8.7	1.4	1.3
K_2O	0.3	0.0	0.0	0.3	0.3	0.3	0.3	1.3	0.2	1.4
MgO	0.4	1.3	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.4
CaO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SrO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BaO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZnO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TiO_2	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
ZrO_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SnO_2	0.10	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Y_2O_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fe_2O_3	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
P_2O_5	0.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SO_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cl	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
MoO_3	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
B_2O_3 + MgO + CaO	2.1	3.5	10.0	10.2	10.2	3.0	6.5	0.2	9.3	6.2
$Al_2O_3 + Li_2O + Na_2O + K_2O$	30.9	35.8	28.8	26.5	27.0	31.1	18.9	36.5	20.4	26.0
R_2O/Al_2O_3	0.98	1.08	1.00	1.01	1.05	0.94	0.91	1.05	0.89	1.28
$Al_2O_3/(R_2O + RO)$	0.99	0.86	1.00	0.98	0.94	1.06	1.10	0.95	1.13	0.76
Na_2O/Li_2O	1.00	0.51	0.43	0.59	0.61	0.97	0.32	1.00	0.18	0.11
Li_2O/Al_2O_3	0.48	0.72	0.70	0.62	0.64	0.47	0.67	0.49	0.74	1.04
Q	−8.25	−26.87	−18.79	−10.34	−11.69	−11.49	21.62	−22.19	10.17	0.51
X	498	813	651	511	514	511	405	596	511	734
Y	19	14	13	14	14	19	16	20	14	12
Z	40	71	66	51	50	42	53	45	65	85
W	372	634	514	399	399	379	368	432	450	642
U	7,954	7,533	8,094	8,119	8,045	8,027	8,427	7,648	8,467	7,831
ρ (g/cm^3)	2.396	2.413	2.330	2.326	2.331	2.385	2.288	2.428	2.283	2.347
Ts (° C.)	914	N.A.	760	791	796	904	910	N.A.	861	N.A.
$\alpha_{300\text{-}380°\ C.}$ ($\times 10^{-7}$/° C.)	N.A.	78.1	65.1	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
$10^{2.5}$ dPa · s (° C.)	1,616	1,461	1,456	1,509	1,523	1,593	1,712	1,574	1,615	1,545
E (GPa)	78	79.4	71	69	70	76	69	80	68	76
CS_K (MPa)	1,186	855	700	706	770	1,152	591	1,204	574	648
DOL_K (μm)	24	11	10	13	14	23	17	26	11	10
CS_{Na} (MPa)	302	556	509	381	389	351	271	365	377	459
$CS30_{Na}$ (MPa)	190	275	166	149	147	201	122	210	120	131
DOC_{Na} (μm)	103	79	60	67	66	92	74	92	60	57
$CTcv_{Na}$ (MPa)	65	80	42	37	35	60	31	66	30	34
DOC_{Na}/DOL_K	4.4	7.5	6.0	5.2	4.8	4.0	4.3	3.5	5.4	5.7
Acid resistance 5 wt % HCl 80° C. 24 h (mg/cm^2)	N.A.	N.A.	39.80	N.A.	3.98	1.58	N.A.	N.A.	N.A.	N.A.
Alkali resistance 5 wt % NaOH 80° C. 6 h (mg/cm^2)	N.A.	N.A.	1.10	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

TABLE 13-continued

Component (mol %)	No. 114	No. 115	No. 116	No. 117	No. 118	No. 119	No. 120	No. 121	No. 122	No. 123
K1c (SEPB) ($MPam^{0.5}$)	N.A.	N.A.	0.81	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Fracture energy γ	N.A.	N.A.	9.24	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

TABLE 14

Component (mol %)	No. 124	No. 125	No. 126	No. 127	No. 128	No. 129	No. 130	No. 131	No. 132	No. 133
SiO_2	64.265	67.465	67.465	62.955	62.955	63.055	63.055	63.055	63.055	61.055
Al_2O_3	13.1	16.0	15.0	13.8	17.8	13.8	15.8	13.8	13.8	15.8
B_2O_3	7.7	1.0	2.0	0.1	0.1	0.0	0.0	0.0	2.0	2.0
Li_2O	8.2	7.5	7.5	8.3	4.3	5.3	4.3	4.3	6.3	6.3
Na_2O	6.1	7.3	7.3	11.1	11.1	11.1	11.1	11.1	11.1	11.1
K_2O	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MgO	0.2	0.3	0.3	0.0	0.0	2.0	2.0	4.0	0.0	0.0
CaO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SrO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BaO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZnO	0.0	0.0	0.0	1.2	1.2	1.2	1.2	1.2	1.2	1.2
TiO_2	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
ZrO_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SnO_2	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Y_2O_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fe_2O_3	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
P_2O_5	0.0	0.0	0.0	2.5	2.5	2.5	2.5	2.5	2.5	2.5
SO_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cl	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MoO_3	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
B_2O_3 + MgO + CaO	7.9	1.3	2.3	0.1	0.1	2.0	2.0	4.0	2.0	2.0
$Al_2O_3 + Li_2O + Na_2O + K_2O$	27.7	31.1	30.1	33.2	33.2	31.2	31.2	29.2	31.2	33.2
R_2O/Al_2O_3	1.11	0.94	1.01	1.41	0.87	1.26	0.97	1.12	1.26	1.10
$Al_2O_3/(R_2O + RO)$	0.89	1.04	0.97	0.71	1.16	0.71	0.91	0.71	0.79	0.91
Na_2O/Li_2O	0.74	0.97	0.97	1.34	2.58	1.76	2.58	2.58	1.76	1.76
Li_2O/Al_2O_3	0.63	0.47	0.50	0.60	0.24	0.46	0.27	0.31	0.46	0.40
Q	−8.58	−7.78	−5.78	−8.79	−12.80	−4.60	−6.60	−0.59	−6.60	−14.60
X	483	515	484	411	325	314	271	216	308	365
Y	15	20	19	20	23	19	21	18	21	21
Z	44	42	40	20	10	6	1	−8	10	14
W	370	388	366	273	180	194	147	114	182	218
U	7,889	8,022	7,936	6,724	7,629	7,043	7,496	7,363	7,003	7,188
ρ (g/cm^3)	2.350	2.397	2.389	2.436	2.432	2.443	2.442	2.452	2.420	2.427
Ts (° C.)	795	942	896	881	949	886	901	906	N.A.	841
$\alpha_{300\text{-}380°\ C.}$ ($\times 10^{-7}$/° C.)	N.A.	N.A.	N.A.	87.4	76.2	85.1	79	83.1	81.7	81.6
$10^{2.5}$ dPa · s (° C.)	1,556	1,637	1,615	1,512	1,629	1,539	1,603	1,559	1,547	1,549
E (GPa)	72	79	77	76	75	77	76	76	73	74
CS_K (MPa)	806	1,239	1,104	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
DOL_K (μm)	15	24	22	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
CS_{Na} (MPa)	363	312	305	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
$CS30_{Na}$ (MPa)	173	203	191	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
DOC_{Na} (μm)	78	109	103	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
$CTcv_{Na}$ (MPa)	44	71	64	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
DOC_{Na}/DOL_K	5.1	4.5	4.6	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Acid resistance 5 wt % HCl 80° C. 24 h (mg/cm^2)	0.77	0.16	0.16	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Alkali resistance 5 wt % NaOH 80° C. 6 h (mg/cm^2)	1.19	0.71	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
K1c (SEPB) ($MPam^{0.5}$)	N.A.	0.80	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Fracture energy γ	N.A.	8.14	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

TABLE 15

Component (mol %)	No. 134	No. 135	No. 136	No. 137	No. 138	No. 139	No. 140	No. 141	No. 142	No. 143
SiO_2	61.055	62.955	60.955	60.955	62.955	64.955	60.955	64.955	62.955	62.955
Al_2O_3	13.8	13.8	15.8	13.8	17.8	15.8	19.8	17.8	19.8	15.8
B_2O_3	4.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

TABLE 15-continued

Component (mol %)	No. 134	No. 135	No. 136	No. 137	No. 138	No. 139	No. 140	No. 141	No. 142	No. 143
Li_2O	6.3	6.3	6.3	6.3	6.3	6.3	6.3	4.3	4.3	6.3
Na_2O	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	13.1
K_2O	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MgO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CaO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SrO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BaO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZnO	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
TiO_2	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
ZrO_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SnO_2	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Y_2O_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fe_2O_3	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
P_2O_5	2.5	4.5	4.5	6.5	0.5	0.5	0.5	0.5	0.5	0.5
SO_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cl	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MoO_3	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
B_2O_3 + MgO + CaO	4.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Al_2O_3 + Li_2O + Na_2O + K_2O	31.2	31.2	33.2	31.2	35.2	33.2	37.2	33.2	35.2	35.2
R_2O/Al_2O_3	1.26	1.26	1.10	1.26	0.98	1.10	0.88	0.87	0.78	1.23
$Al_2O_3/(R_2O + RO)$	0.79	0.79	0.91	0.79	1.02	0.91	1.14	1.16	1.29	0.81
Na_2O/Li_2O	1.76	1.76	1.76	1.76	1.76	1.76	1.76	2.58	2.58	2.08
Li_2O/Al_2O_3	0.46	0.46	0.40	0.46	0.35	0.40	0.32	0.24	0.22	0.40
Q	−10.60	−2.40	−10.40	−2.00	−19.20	−11.20	−27.20	−13.20	−21.20	−16.20
X	305	314	371	317	422	365	479	322	379	320
Y	19	21	21	21	22	22	22	24	24	23
Z	9	10	15	10	20	15	24	10	15	4
W	173	190	227	190	263	227	299	180	217	168
U	7,016	6,736	6,922	6,482	7,617	7,431	7,802	7,884	8,070	7,114
ρ (g/cm^3)	2.413	2.415	2.425	2.404	2.450	2.445	2.461	2.443	2.458	2.460
Ts (° C.)	825	N.A.	866	846	N.A.	N.A.	927	968	961	823
$\alpha_{300\text{-}380°\ C.}$ (×10^{-7}/° C.)	81.2	82.8	82.7	82.4	81	83.6	79.1	75.3	71	89.2
$10^{2.5}$ dPa · s (° C.)	1,518	1,580	1,576	1,572	1,585	1,598	1,558	1,635	1,607	1,553
E (GPa)	72	73	73	70	78	79	81	79	80	78
CS_K (MPa)	N.A.	N.A.	N.A.	N.A.	N.A.	1,125	1,455	1,343	1,348	945
DOL_K (μm)	N.A.	N.A.	N.A.	N.A.	N.A.	20	18	21	17	20
CS_{Na} (MPa)	N.A.	N.A.	N.A.	N.A.	N.A.	249	289	209	176	216
$CS30_{Na}$ (MPa)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
DOC_{Na} (μm)	N.A.	N.A.	N.A.	N.A.	N.A.	115	126	132	107	111
$CTcv_{Na}$ (MPa)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
DOC_{Na}/DOL_K	N.A.	N.A.	N.A.	N.A.	N.A.	5.6	7.2	6.3	6.2	5.6
Acid resistance 5 wt % HCl 80° C. 24 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Alkali resistance 5 wt % NaOH 80° C. 6 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
K1c (SEPB) (MPam$^{0.5}$)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Fracture energy γ	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

TABLE 16

Component (mol %)	No. 144	No. 145	No. 146	No. 147	No. 148	No. 149	No. 150	No. 151	No. 152	No. 153
SiO_2	60.955	64.955	62.955	61.055	63.055	59.055	61.055	59.055	63.055	61.055
Al_2O_3	17.8	17.8	19.8	17.8	15.8	19.8	15.8	17.8	17.8	19.8
B_2O_3	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Li_2O	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3
Na_2O	13.1	9.1	9.1	11.1	11.1	11.1	13.1	13.1	9.1	9.1
K_2O	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MgO	0.0	0.0	0.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
CaO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SrO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BaO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZnO	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
TiO_2	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
ZrO_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SnO_2	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Y_2O_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fe_2O_3	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002

TABLE 16-continued

Component (mol %)	No. 144	No. 145	No. 146	No. 147	No. 148	No. 149	No. 150	No. 151	No. 152	No. 153
P_2O_5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
SO_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cl	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MoO_3	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
B_2O_3 + MgO + CaO	0.1	0.1	0.1	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Al_2O_3 + Li_2O + Na_2O + K_2O	37.2	33.2	35.2	35.2	33.2	37.2	35.2	37.2	33.2	35.2
R_2O/Al_2O_3	1.09	0.87	0.78	0.98	1.10	0.88	1.23	1.09	0.87	0.78
$Al_2O_3/(R_2O + RO)$	0.92	1.16	1.29	0.92	0.81	1.02	0.74	0.83	1.02	1.14
Na_2O/Li_2O	2.08	1.44	1.44	1.76	1.76	1.76	2.08	2.08	1.44	1.44
Li_2O/Al_2O_3	0.35	0.35	0.32	0.35	0.40	0.32	0.40	0.35	0.35	0.32
Q	−24.20	−14.20	−22.20	−21.00	−13.00	−29.00	−18.00	−26.00	−16.00	−24.00
X	377	468	525	425	368	482	322	379	470	527
Y	23	22	22	20	20	20	20	20	19	19
Z	8	31	35	15	11	20	−1	4	26	31
W	204	322	358	266	230	303	171	208	325	361
U	7,300	7,934	8,119	7,669	7,484	7,854	7,167	7,352	7,986	8,171
ρ (g/cm^3)	2.464	2.440	2.455	2.469	2.460	2.478	2.473	2.480	2.457	2.470
Ts (° C.)	872	947	942	N.A.	N.A.	N.A.	811	N.A.	N.A.	911
$\alpha_{300\text{-}380°\ C.}$ (×10^{-7}/° C.)	89.6	72.2	69.3	81.5	83.4	79	90.3	88.6	72.6	69.1
$10^{2.5}$ dPa · s (° C.)	1,553	1,607	1,574	1,533	1,544	1,516	1,503	1,499	1,557	1,528
E (GPa)	79	80	82	81	80	82	80	81	82	83
CS_K (MPa)	1,154	1,323	1,330	1,313	1,148	1,371	1,050	1,222	1,301	1,312
DOL_K (μm)	21	17	13	14	16	12	16	16	12	10
CS_{Na} (MPa)	N.A.	N.A.	257	264	N.A.	N.A.	238	N.A.	N.A.	284
$CS30_{Na}$ (MPa)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
DOC_{Na} (μm)	N.A.	N.A.	130	103	N.A.	N.A.	101	N.A.	N.A.	100
$CTcv_{Na}$ (MPa)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
DOC_{Na}/DOL_K	N.A.	N.A.	9.9	7.3	N.A.	N.A.	6.4	N.A.	N.A.	10.2
Acid resistance	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
5 wt % HCl 80° C. 24 h (mg/cm^2)										
Alkali resistance	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
5 wt % NaOH 80° C. 6 h (mg/cm^2)										
K1c (SEPB) (MPam$^{0.5}$)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Fracture energy γ	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

TABLE 17

Component (mol %)	No. 154	No. 155	No. 156	No. 157	No. 158	No. 159	No. 160	No. 161	No. 162	No. 163
SiO_2	61.055	61.055	59.055	63.055	61.055	59.055	59.055	57.055	61.055	59.055
Al_2O_3	17.8	15.8	17.8	17.8	19.8	17.8	15.8	17.8	17.8	19.8
B_2O_3	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Li_2O	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3
Na_2O	11.1	13.1	13.1	9.1	9.1	11.1	13.1	13.1	9.1	9.1
K_2O	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MgO	0.0	0.0	0.0	0.0	0.0	2.0	2.0	2.0	2.0	2.0
CaO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SrO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BaO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZnO	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
TiO_2	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
ZrO_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SnO_2	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Y_2O_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fe_2O_3	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
P_2O_5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
SO_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cl	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MoO_3	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
B_2O_3 + MgO + CaO	2.0	2.0	2.0	2.0	2.0	4.0	4.0	4.0	4.0	4.0
Al_2O_3 + Li_2O + Na_2O + K_2O	35.2	35.2	37.2	33.2	35.2	35.2	35.2	37.2	33.2	35.2
R_2O/Al_2O_3	0.98	1.23	1.09	0.87	0.78	0.98	1.23	1.09	0.87	0.78
$Al_2O_3/(R_2O + RO)$	1.02	0.81	0.92	1.16	1.29	0.92	0.74	0.83	1.02	1.14
Na_2O/Li_2O	1.76	2.08	2.08	1.44	1.44	1.76	2.08	2.08	1.44	1.44
Li_2O/Al_2O_3	0.35	0.40	0.35	0.35	0.32	0.35	0.40	0.35	0.35	0.32
Q	−23.00	−20.00	−28.00	−18.00	−26.00	−25.00	−22.00	−30.00	−20.00	−28.00
X	419	316	373	465	521	421	319	376	467	524
Y	21	22	22	21	21	19	19	19	18	18

TABLE 17-continued

Component (mol %)	No. 154	No. 155	No. 156	No. 157	No. 158	No. 159	No. 160	No. 161	No. 162	No. 163
Z	19	3	8	30	35	15	−1	3	26	30
W	255	160	196	313	350	257	162	199	316	352
U	7,629	7,126	7,312	7,946	8,131	7,682	7,179	7,365	7,998	8,184
ρ (g/cm^3)	2.440	2.452	2.454	2.429	2.445	2.459	2.465	2.471	2.446	2.460
Ts (° C.)	872	788	838	897	897	844	777	809	865	873
$\alpha_{300\text{-}380^\circ C.}$ (×10^{-7}/° C.)	79.4	87.7	87.5	70.5	68.4	80	89	87.7	71.5	69.4
$10^{2.5}$ dPa · s (° C.)	1,541	1,513	1,520	1,564	1,530	1,494	1,464	1,462	1,514	1,483
E (GPa)	77	77	78	78	80	80	78	79	80	81
CS_K (MPa)	1,236	1,136	932	1,244	1,246	1,263	998	1,171	1,223	1,265
DOL_K (μm)	17	19	17	14	11	13	15	15	11	8
CS_{Na} (MPa)	260	225	N.A.	N.A.	259	N.A.	N.A.	N.A.	N.A.	N.A.
$CS30_{Na}$ (MPa)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
DOC_{Na} (μm)	99	105	N.A.	N.A.	139	N.A.	N.A.	N.A.	N.A.	N.A.
$CTcv_{Na}$ (MPa)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
DOC_{Na}/DOL_K	6.0	5.6	N.A.	N.A.	13.1	N.A.	N.A.	N.A.	N.A.	N.A.
Acid resistance 5 wt % HCl 80° C. 24 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Alkali resistance 5 wt % NaOH 80° C. 6 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
K1c (SEPB) (MPam$^{0.5}$)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Fracture energy γ	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

TABLE 18

Component (mol %)	No. 164	No. 165	No. 166	No. 167	No. 168	No. 169	No. 170	No. 171	No. 172	No. 173
SiO_2	62.955	62.955	62.955	61.055	61.055	61.055	61.055	60.955	60.955	60.955
Al_2O_3	17.8	13.8	19.8	17.8	13.8	19.8	19.8	17.8	15.8	13.8
B_2O_3	0.1	0.1	0.1	2.0	2.0	2.0	2.0	0.1	0.1	0.1
Li_2O	4.3	8.3	8.3	4.3	8.3	4.3	8.3	4.3	6.3	8.3
Na_2O	13.1	13.1	7.1	13.1	13.1	11.1	7.1	13.1	13.1	13.1
K_2O	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MgO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CaO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SrO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BaO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZnO	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
TiO_2	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
ZrO_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SnO_2	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Y_2O_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fe_2O_3	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
P_2O_5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	2.5	2.5	2.5
SO_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cl	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MoO_3	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
B_2O_3 + MgO + CaO	0.1	0.1	0.1	2.0	2.0	2.0	2.0	0.1	0.1	0.1
$Al_2O_3 + Li_2O + Na_2O + K_2O$	35.2	35.2	35.2	35.2	35.2	35.2	35.2	35.2	35.2	35.2
R_2O/Al_2O_3	0.98	1.55	0.78	0.98	1.55	0.78	0.78	0.98	1.23	1.55
$Al_2O_3/(R_2O + RO)$	1.02	0.64	1.29	1.02	0.64	1.29	1.29	1.02	0.81	0.64
Na_2O/Li_2O	3.05	1.58	0.86	3.05	1.58	2.58	0.86	3.05	2.08	1.58
Li_2O/Al_2O_3	0.24	0.60	0.42	0.24	0.60	0.22	0.42	0.24	0.40	0.60
Q	−18.20	−14.20	−23.20	−22.00	−18.00	−25.00	−27.00	−17.80	−15.80	−13.80
X	276	363	671	273	359	376	667	279	323	366
Y	24	21	20	23	20	23	19	24	22	21
Z	−1	9	56	−2	8	14	56	−1	4	9
W	122	215	500	113	206	208	491	122	168	215
U	7,567	6,662	8,169	7,579	6,674	8,081	8,181	7,312	6,860	6,407
ρ (g/cm^3)	2.454	2.463	2.450	2.442	2.460	2.447	2.440	2.446	2.450	2.451
Ts (° C.)	942	738	930	891	718	914	887	926	842	862
$\alpha_{300\text{-}380^\circ C.}$ (×10^{-7}/° C.)	83.5	94	66	82.8	91.4	70.3	65.8	84.6	90.5	93.3
$10^{2.5}$ dPa · s (° C.)	1,620	1,461	1,552	1,564	1,441	1,559	1,510	1,603	1,550	1,468
E (GPa)	79	78	83	75	79	78	81	75	76	77
CS_K (MPa)	1,600	711	1,521	1,474	702	1,488	1,441	1,399	1,200	1,080
DOL_K (μm)	24	16	10	21	13	14	9	27	26	25
CS_{Na} (MPa)	192	213	315	163	205	208	315	171	167	161
$CS30_{Na}$ (MPa)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

TABLE 18-continued

Component (mol %)	No. 164	No. 165	No. 166	No. 167	No. 168	No. 169	No. 170	No. 171	No. 172	No. 173
DOC_{Na} (μm)	123	99	111	132	96	96	101	138	136	107
$CTcv_{Na}$ (MPa)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
DOC_{Na}/DOL_K	5.0	6.2	11.2	6.3	7.4	7.1	11.7	5.1	5.2	4.3
Acid resistance 5 wt % HCl 80° C. 24 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Alkali resistance 5 wt % NaOH 80° C. 6 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
K1c (SEPB) ($MPam^{0.5}$)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Fracture energy γ	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

TABLE 19

Component (mol %)	No. 174	No. 175	No. 176	No. 177	No. 178	No. 179	No. 180	No. 181	No. 182	No. 183
SiO_2	60.955	60.955	60.955	61.055	61.055	61.055	61.055	64.155	60.955	60.955
Al_2O_3	19.8	19.8	19.8	17.8	13.8	19.8	19.8	17.8	17.8	17.8
B_2O_3	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.1
Li_2O	4.3	6.3	8.3	4.3	8.3	4.3	8.3	6.3	6.3	6.3
Na_2O	11.1	9.1	7.1	13.1	13.1	11.1	7.	11.1	11.1	11.1
K_2O	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0
MgO	0.0	0.0	0.0	2.0	2.0	2.0	2.0	0.0	0.0	0.0
CaO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SrO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BaO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZnO	1.2	1.2	1.2	1.2	1.2	1.2	1.	0.0	1.2	1.2
TiO_2	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
ZrO_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SnO_2	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Y_2O_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0
Fe_2O_3	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
P_2O_5	2.5	2.5	2.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
SO_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cl	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MoO_3	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
$B_2O_3 + MgO + CaO$	0.1	0.1	0.1	2.0	2.0	2.0	2.0	0.1	0.1	0.1
$Al_2O_3 + Li_2O + Na_2O + K_2O$	35.2	35.2	35.2	35.2	35.2	35.2	35.2	35.2	37.2	35.2
R_2O/Al_2O_3	0.78	0.78	0.78	0.98	1.55	0.78	0.78	0.98	1.09	0.98
$Al_2O_3/(R_2O + RO)$	1.29	1.29	1.29	0.92	0.59	1.14	1.14	1.02	0.92	1.02
Na_2O/Li_2O	2.58	1.44	0.86	3.05	1.58	2.58	0.86	1.76	1.76	1.76
Li_2O/Al_2O_3	0.22	0.32	0.42	0.24	0.60	0.22	0.42	0.35	0.35	0.35
Q	−20.80	−21.80	−22.80	−20.00	−16.00	−23.00	−25.00	−18.00	−23.20	−21.20
X	382	528	674	279	365	382	673	420	425	425
Y	23	21	19	22	19	21	17	22	22	22
Z	14	35	56	−6	4	10	52	20	19	19
W	217	358	499	125	218	220	503	263	263	263
U	7,815	7,865	7,914	7,619	6,714	8,122	8,221	7,722	7,325	7,442
ρ (g/cm^3)	2.443	2.440	2.437	2.470	2.475	2.473	2.466	2.424	2.464	2.563
Ts (° C.)	950	931	917	900	738	930	900	953	870	888
$\alpha_{300\text{-}380°\ C.}$ ($\times 10^{-7}$/° C.)	71.3	69.9	67.6	82.9	95.5	71.7	68.8	82.7	93.4	80.5
$10^{2.5}$ dPa · s (° C.)	1,592	1,567	1,541	1,560	1,423	1,555	1,506	1,612	1,569	1,487
E (GPa)	77	79	80	79	80	81	84	78	79	83
CS_K (MPa)	1,411	1,397	1,376	1,533	905	1,515	1,460	1,488	1,302	1,549
DOL_K (μm)	19	16	11	17	15	13	6	23	26	14
CS_{Na} (MPa)	152	216	324	185	213	174	290	266	207	196
$CS30_{Na}$ (MPa)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
DOC_{Na} (μm)	132	134	116	104	82	99	101	137	103	102
$CTcv_{Na}$ (MPa)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
DOC_{Na}/DOL_K	6.8	8.4	10.3	6.0	5.6	7.9	16.3	5.9	4.0	7.6
Acid resistance 5 wt % HCl 80° C. 24 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Alkali resistance 5 wt % NaOH 80° C. 6 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
K1c (SEPB) ($MPam^{0.5}$)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Fracture energy γ	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

TABLE 20

Component (mol %)	No. 184	No. 185	No. 186	No. 187	No. 188	No. 189	No. 190	No. 191	No. 192	No. 193
SiO_2	62.955	59.055	58.955	58.955	60.055	60.055	59.955	59.955	61.055	60.955
Al_2O_3	17.8	19.8	19.8	17.8	19.8	17.8	19.8	17.8	18.8	18.8
B_2O_3	0.1	2.0	0.1	0.1	2.0	2.0	0.1	0.1	2.0	0.1
Li_2O	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3
Na_2O	11.1	11.1	11.1	13.1	10.1	12.1	10.1	12.1	10.1	10.1
K_2O	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MgO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CaO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SrO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BaO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZnO	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
TiO_2	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
ZrO_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SnO_2	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Y_2O_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fe_2O_3	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
P_2O_5	0.5	0.5	2.5	2.5	0.5	0.5	2.5	2.5	0.5	2.5
SO_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cl	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MoO_3	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
B_2O_3 + MgO + CaO	0.1	2.0	0.1	0.1	2.0	2.0	0.1	0.1	2.0	0.1
$Al_2O_3 + Li_2O + Na_2O + K_2O$	35.2	37.2	37.2	37.2	36.2	36.2	36.2	36.2	35.2	35.2
R_2O/Al_2O_3	0.98	0.88	0.88	1.09	0.83	1.03	0.83	1.03	0.87	0.87
$Al_2O_3/(R_2O + RO)$	1.02	1.14	1.14	0.92	1.21	0.97	1.21	0.97	1.15	1.15
Na_2O/Li_2O	1.76	1.76	1.76	2.08	1.60	1.92	1.60	1.92	1.60	1.60
Li_2O/Al_2O_3	0.35	0.32	0.32	0.35	0.32	0.35	0.32	0.35	0.34	0.34
Q	−19.20	−31.00	−26.80	−23.80	−28.50	−25.50	−24.30	−21.30	−24.50	−20.30
X	422	476	482	380	499	396	505	402	470	476
Y	22	21	22	22	21	21	22	22	21	22
Z	20	24	24	8	29	13	30	14	27	27
W	263	291	299	204	320	225	329	234	302	310
U	7,617	7,814	7,548	7,045	7,973	7,470	7,706	7,204	7,880	7,613
ρ (g/cm^3)	2.601	2.451	2.453	2.457	2.448	2.445	2.447	2.450	2.440	2.440
Ts (° C.)	884	882	913	871	890	855	924	889	890	923
$\alpha_{300\text{-}380^\circ C.}$ ($\times 10^{-7}$/° C.)	83.7	77.6	79.6	89.5	73.6	85.1	75	86.6	74.6	76.9
$10^{2.5}$ dPa · s (° C.)	1,485	1,519	1,547	1,541	1,525	1,529	1,557	1,560	1,540	1,578
E (GPa)	82	78	78	77	79	74	79	77	78	78
CS_K (MPa)	1,494	1,486	1,453	1,297	1,492	1,421	1,438	1,349	1,476	1,395
DOL_K (μm)	13	15	18	26	12	16	16	23	14	18
CS_{Na} (MPa)	193	280	254	217	263	260	237	225	259	245
$CS30_{Na}$ (MPa)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
DOC_{Na} (μm)	102	115	134	127	111	112	131	127	112	134
$CTcv_{Na}$ (MPa)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
DOC_{Na}/DOL_K	7.8	7.8	7.3	4.9	9.3	6.8	8.0	5.6	8.3	7.3
Acid resistance 5 wt % HCl 80° C. 24 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Alkali resistance 5 wt % NaOH 80° C. 6 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
K1c (SEPB) (MPam$^{0.5}$)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Fracture energy γ	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

TABLE 21

Component (mol %)	No. 194	No. 195	No. 196	No. 197	No. 198	No. 199	No. 200	No. 201	No. 202	No. 203
SiO_2	59.055	70.005	63.205	62.695	67.895	63.376	61.965	60.277	60.242	60.173
Al_2O_3	18.8	10.0	14.3	15.5	8.1	15.7	17.2	18.9	18.9	18.9
B_2O_3	2.0	0.0	0.0	7.0	0.3	3.2	1.7	0.2	0.2	0.2
Li_2O	6.3	10.0	13.5	7.0	0.0	3.6	5.4	7.2	7.2	7.2
Na_2O	12.1	3.0	2.0	4.1	14.3	4.0	6.0	8.2	8.2	8.2
K_2O	0.0	1.0	5.0	0.1	1.1	0.2	0.3	0.4	0.4	0.4
MgO	0.0	5.0	1.0	1.0	5.2	2.4	1.5	0.3	0.3	0.3
CaO	0.0	0.0	0.0	1.5	3.0	3.8	1.9	0.0	0.0	0.0
SrO	0.0	0.0	0.0	1.1	0.0	0.2	0.1	0.0	0.0	0.0
BaO	0.0	0.0	0.0	0.0	0.0	1.3	0.6	0.0	0.0	0.0
ZnO	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TiO_2	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.070	0.105	0.174
ZrO_2	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TABLE 21-continued

Component (mol %)	No. 194	No. 195	No. 196	No. 197	No. 198	No. 199	No. 200	No. 201	No. 202	No. 203
SnO_2	0.04	0.00	0.00	0.00	0.10	0.07	0.06	0.05	0.05	0.05
Y_2O_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fe_2O_3	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
P_2O_5	0.5	0.0	0.0	0.0	0.0	2.1	3.2	4.3	4.3	4.3
SO_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cl	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1
MoO_3	0.001	0.001	0.001	0.001	0.001	0.000	0.001	0.001	0.001	0.001
B_2O_3 + MgO + CaO	2.0	5.0	1.0	9.5	8.5	9.4	5.1	0.5	0.5	0.5
$Al_2O_3 + Li_2O + Na_2O + K_2O$	37.2	24.0	34.8	26.7	23.5	23.5	28.9	34.7	34.7	34.7
R_2O/Al_2O_3	0.98	1.40	1.43	0.72	1.90	0.50	0.68	0.84	0.84	0.84
$Al_2O_3/(R_2O + RO)$	1.02	0.53	0.67	1.05	0.34	1.01	1.09	1.17	1.17	1.17
Na_2O/Li_2O	1.92	0.30	0.15	0.59	—	1.11	1.11	1.14	1.14	1.14
Li_2O/Al_2O_3	0.34	1.00	0.94	0.45	0.00	0.23	0.31	0.38	0.38	0.38
Q	−29.50	14.51	−14.70	−11.06	20.75	2.20	−7.59	−18.56	−18.60	−18.67
X	425	577	898	546	−224	406	487	570	570	570
Y	21	11	12	13	16	11	15	20	20	20
Z	16	54	95	50	−69	26	34	42	42	42
W	243	520	766	411	−292	271	340	405	405	405
U	7,563	7,754	7,154	8,715	7,272	8,996	8,317	7,614	7,611	7,605
ρ (g/cm^3)	2.450	2.427	2.447	2.403	2.467	2.465	2.433	2.404	2.403	2.404
Ts (° C.)	864	N.A.	N.A.	839	798	902	902	922	921	921
$\alpha_{300\text{-}380^\circ C.}$ (×10^{-7}/° C.)	84.5	65.6	85	58.6	89.7	53.9	63	75.2	72.4	74.5
$10^{2.5}$ dPa · s (° C.)	1,521	1,526	1,468	1,492	1,484	1,551	1,570	1,580	1,576	1,579
E (GPa)	78	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	75	75	75
CS_K (MPa)	1,433	N.A.	N.A.	N.A.	905	662	1,105	N.A.	N.A.	N.A.
DOL_K (μm)	14	N.A.	N.A.	N.A.	25	N.A.	13	N.A.	N.A.	N.A.
CS_{Na} (MPa)	280	N.A.	N.A.	N.A.	N.A.	112	272	N.A.	N.A.	290
$CS30_{Na}$ (MPa)	N.A.	N.A.	N.A.	N.A.	N.A.	48	138	N.A.	N.A.	N.A.
DOC_{Na} (μm)	118	N.A.	N.A.	N.A.	N.A.	79	95	N.A.	N.A.	N.A.
$CTcv_{Na}$ (MPa)	N.A.	N.A.	N.A.	N.A.	N.A.	6	15	N.A.	N.A.	N.A.
DOC_{Na}/DOL_K	8.3	N.A.	N.A.	N.A.	N.A.	N.A.	7.3	N.A.	N.A.	N.A.
Acid resistance 5 wt % HCl 80° C. 24 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Alkali resistance 5 wt % NaOH 80° C. 6 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
K1c (SEPB) (MPam$^{0.5}$)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Fracture energy γ	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

TABLE 22

Component (mol %)	No. 204	No. 205	No. 206	No. 207	No. 208	No. 209	No. 210	No. 211	No. 212	No. 213
SiO_2	64.42	64.507	69.417	69.047	66.227	61.647	65.647	56.647	63.647	68.817
Al_2O_3	13.4	11.7	11.1	12.4	11.26	25	21	25	23	13.63
B_2O_3	1.2	0.0	3.4	0.0	0.0	0.2	0.2	0.2	0.2	1.7
Li_2O	3.5	10.6	8.3	10.9	10.27	6.5	6.5	6.5	6.5	7.51
Na_2O	10.9	9.5	2.5	4.7	5.45	6.00	6.00	11.00	6.00	7.49
K_2O	0.4	0.3	0.2	1.1	1.43	0.3	0.3	0.3	0.3	0.3
MgO	2.4	0.8	1.1	0.1	3.1	0.2	0.2	0.2	0.2	0.4
CaO	0.0	0.2	2.9	0.1	0.3	0.0	0.0	0.0	0.0	0.0
SrO	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BaO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZnO	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TiO_2	1.587	0.010	0.010	0.1	0.1	0.0	0.0	0.0	0.0	0.0
ZrO_2	0.0	1.8	0.1	0.2	1.3	0.0	0.0	0.0	0.0	0.0
SnO_2	0.10	0.00	0.09	0.00	0.00	0.05	0.05	0.05	0.05	0.05
Y_2O_3	0.0	0.0	0.0	1.3	0.53	0.0	0.0	0.0	0.0	0.0
Fe_2O_3	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
P_2O_5	2.0	0.4	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SO_3	0.0	0.0	0.0	0.01	0.0	0.0	0.0	0.0	0.0	0.0
Cl	0.1	0.0	0.3	0.02	0.1	0.1	0.1	0.1	0.1	0.1
MoO_3	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
B_2O_3 + MgO + CaO	3.6	1.0	7.4	0.2	3.33	0.4	0.4	0.4	0.4	2.1
$Al_2O_3 + Li_2O + Na_2O + K_2O$	28.2	32.1	22.1	29.1	28.4	37.8	33.8	42.8	35.8	28.9
R_2O/Al_2O_3	1.10	1.74	0.99	1.35	1.52	0.51	0.61	0.71	0.56	1.12
$Al_2O_3/(R_2O + RO)$	0.78	0.55	0.73	0.73	0.55	1.89	1.59	1.37	1.74	0.78
Na_2O/Li_2O	3.11	0.90	0.30	0.43	0.53	0.92	0.92	1.69	0.92	1.00
Li_2O/Al_2O_3	0.26	0.91	0.75	0.88	0.91	0.26	0.31	0.26	0.28	0.55

TABLE 22-continued

Component (mol %)	No. 204	No. 205	No. 206	No. 207	No. 208	No. 209	No. 210	No. 211	No. 212	No. 213
Q	1.67	−5.86	12.53	1.90	2.30	−35.85	−19.85	−48.35	−27.85	−0.33
X	166	504	535	647	571	752	638	638	695	442
Y	20	17	10	16	13	21	21	22	21	19
Z	−8	33	52	65	48	65	56	37	61	35
W	72	377	433	543	477	551	479	405	515	337
U	7,389	6,660	8,277	7,388	7,249	9,187	8,816	8,395	9,002	7,777
ρ (g/cm^3)	2.424	2.487	2.403	2.476	2.487	N.A.	2.434	2.477	2.451	2.391
Ts (° C.)	898	743	807	N.A.	787	N.A.	N.A.	N.A.	N.A.	N.A.
$\alpha_{300\text{-}380^\circ C.}$ (×10^{-7}/° C.)	80.3	89.2	57.8	75.7	79.2	N.A.	N.A.	N.A.	N.A.	N.A.
$10^{2.5}$ dPa · s (° C.)	1,601	1,420	1,537	1,516	1,469	N.A.	1,579	1,535	1,512	1,624
E (GPa)	73	82	79	82	83	N.A.	84	84	86	77
CS_K (MPa)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	1,276	633	1,312	904
DOL_K (μm)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	11	13	8	20
CS_{Na} (MPa)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	207	192	206	313
$CS30_{Na}$ (MPa)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	132	128	128	171
DOC_{Na} (μm)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	108	115	103	88
$CTcv_{Na}$ (MPa)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	40	45	38	47
DOC_{Na}/DOL_K	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	10.1	8.5	12.4	4.5
Acid resistance 5 wt % HCl 80° C. 24 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Alkali resistance 5 wt % NaOH 80° C. 6 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
K1c (SEPB) (MPam$^{0.5}$)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Fracture energy γ	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

TABLE 23

Component (mol %)	No. 214	No. 215	No. 216	No. 217	No. 218	No. 219	No. 220	No. 221	No. 222	No. 223
SiO_2	64.817	68.517	64.817	67.217	64.817	68.817	64.817	68.817	64.817	67.117
Al_2O_3	17.63	15.63	15.63	15.63	15.63	15.63	15.63	15.63	15.63	15.63
B_2O_3	1.7	0.0	3.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
Li_2O	7.51	7.51	7.51	7.51	7.51	5.51	9.51	7.51	7.51	7.51
Na_2O	7.49	7.49	7.49	7.49	7.49	7.49	7.49	5.49	9.49	7.49
K_2O	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.0
MgO	0.4	0.4	0.4	0.0	2.4	0.4	0.4	0.4	0.4	0.4
CaO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SrO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BaO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZnO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TiO_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZrO_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SnO_2	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Y_2O_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fe_2O_3	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
P_2O_5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SO_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cl	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
MoO_3	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
B_2O_3 + MgO + CaO	2.1	0.4	4.1	1.7	4.1	2.1	2.1	2.1	2.1	2.1
Al_2O_3 + Li_2O + Na_2O + K_2O	32.9	30.9	30.9	30.9	30.9	28.9	32.9	28.9	32.9	30.6
R_2O/Al_2O_3	0.87	0.98	0.98	0.98	0.98	0.85	1.11	0.85	1.11	0.96
$Al_2O_3/(R_2O + RO)$	1.01	1.00	0.81	0.92	0.81	1.01	0.81	1.01	0.81	0.91
Na_2O/Li_2O	1.00	1.00	1.00	1.00	1.00	1.36	0.79	0.73	1.26	1.00
Li_2O/Al_2O_3	0.43	0.48	0.48	0.48	0.48	0.35	0.61	0.48	0.48	0.48
Q	−16.33	−4.93	−12.33	−7.93	−10.33	−2.33	−14.33	−3.33	−13.33	−7.73
X	556	502	496	499	502	399	599	545	454	499
Y	19	20	18	20	17	21	18	19	20	19
Z	44	40	39	41	35	30	49	51	29	40
W	410	381	364	373	376	291	456	432	315	373
U	8,147	7,951	7,974	7,951	8,015	8,229	7,695	8,279	7,645	8,006
ρ (g/cm^3)	2.409	2.402	2.385	2.391	2.414	2.390	2.408	2.385	2.415	2.393
Ts (° C.)	929	N.A.	871	924	N.A.	964	N.A.	949	N.A.	921
$\alpha_{300\text{-}380^\circ C.}$ (×10^{-7}/° C.)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
$10^{2.5}$ dPa · s (° C.)	1,588	1,653	1,571	1,630	1,560	1,662	1,550	1,638	1,575	1,618
E (GPa)	79	79	76	77	80	77	80	79	78	78
CS_K (MPa)	1,284	1,243	1,082	1,153	1,202	1,135	982	1,126	991	1,185

TABLE 23-continued

Component (mol %)	No. 214	No. 215	No. 216	No. 217	No. 218	No. 219	No. 220	No. 221	No. 222	No. 223
DOL_K (μm)	20	27	21	25	16	24	17	20	21	23
CS_{Na} (MPa)	329	314	328	318	331	235	387	351	326	322
$CS30_{Na}$ (MPa)	192	204	196	206	184	142	204	199	176	199
DOC_{Na} (μm)	95	108	98	110	89	99	83	91	87	100
$CTcv_{Na}$ (MPa)	60	74	56	65	53	43	62	59	50	68
DOC_{Na}/DOL_K	4.8	4.0	4.8	4.3	5.4	4.2	5.0	4.6	4.2	4.4
Acid resistance 5 wt % HCl 80° C. 24 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Alkali resistance 5 wt % NaOH 80° C. 6 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
K1c (SEPB) ($MPam^{0.5}$)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Fracture energy γ	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

TABLE 24

Component (mol %)	No. 224	No. 225	No. 226	No. 227	No. 228	No. 229	No. 230	No. 231	No. 232
SiO_2	64.817	64.817	62.817	62.157	60.197	58.237	56.277	54.937	54.937
Al_2O_3	15.63	15.63	15.63	18.01	19.01	20.01	21.01	20.01	20.01
B_2O_3	1.7	1.7	1.7	1.7	1.7	1.7	1.7	5.0	5.0
Li_2O	7.51	7.51	7.51	8.65	9.13	9.61	10.09	9.61	12.01
Na_2O	7.49	7.49	7.49	8.63	9.11	9.59	10.07	9.59	7.19
K_2O	2.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
MgO	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
CaO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SrO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BaO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZnO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TiO_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZrO_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SnO_2	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Y_2O_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fe_2O_3	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
P_2O_5	0.0	2.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0
SO_3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cl	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
MoO_3	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
B_2O_3 + MgO + CaO	2.1	2.1	2.1	2.1	2.1	2.1	2.1	5.4	5.4
$Al_2O_3 + Li_2O + Na_2O + K_2O$	32.9	30.9	30.9	35.6	37.6	39.5	41.5	39.5	39.5
R_2O/Al_2O_3	1.11	0.98	0.98	0.98	0.98	0.97	0.97	0.97	0.97
$Al_2O_3/(R_2O + RO)$	0.81	0.90	0.90	0.92	0.92	0.93	0.93	0.80	0.80
Na_2O/Li_2O	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.60
Li_2O/Al_2O_3	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.60
Q	−12.33	−7.93	−7.53	−24.12	−30.76	−37.40	−44.04	−44.00	−45.20
X	502	502	505	598	639	681	723	675	850
Y	19	19	18	19	19	18	18	17	14
Z	40	40	39	44	46	48	50	47	72
W	373	373	373	430	454	478	502	463	633
U	7,670	7,707	7,452	7,850	7,802	7,755	7,707	7,775	7,835
ρ (g/cm^3)	2.413	2.385	2.377	2.418	2.428	2.436	2.444	2.424	2.420
Ts (° C.)	840	896	877	884	N.A.	N.A.	N.A.	N.A.	N.A.
$\alpha_{300\text{-}380°\ C.}$ ($\times 10^{-7}$/° C.)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
$10^{2.5}$ dPa · s (° C.)	1,596	1,614	1,604	1,546	N.A.	N.A.	N.A.	N.A.	N.A.
E (GPa)	78	75	73	80	80	80	81	79	81
CS_K (MPa)	926	1,000	864	1,264	1,297	1,336	1,347	1,240	1,139
DOL_K (μm)	27	27	30	21	20	19	19	16	12
CS_{Na} (MPa)	280	270	248	405	418	456	496	463	655
$CS30_{Na}$ (MPa)	134	174	152	233	240	255	278	230	299
DOC_{Na} (μm)	77	108	99	92	92	90	90	79	75
$CTcv_{Na}$ (MPa)	37	59	52	72	74	76	80	63	72
DOC_{Na}/DOL_K	2.9	4.0	3.3	4.3	4.5	4.7	4.9	5.1	6.3
Acid resistance 5 wt % HCl 80° C. 24 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

TABLE 24-continued

Component (mol %)	No. 224	No. 225	No. 226	No. 227	No. 228	No. 229	No. 230	No. 231	No. 232
Alkali resistance 5 wt % NaOH 80° C. 6 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
K1c (SEPB) ($MPam^{0.5}$)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Fracture energy γ	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

TABLE 25

Component (mol %)	No. 233	No. 234	No. 235	No. 236	No. 237
SiO_2	68.515	68.515	68.515	68.515	68.515
Al_2O_3	13.63	11.63	15.61	15.61	13.61
B_2O_3	2.0	4.0	1.5	3.5	3.5
Li_2O	7.51	7.51	7.51	7.51	7.51
Na_2O	7.49	7.49	6.01	4.01	6.01
K_2O	0.3	0.3	0.3	0.3	0.3
MgO	0.4	0.4	0.4	0.4	0.4
CaO	0.0	0.0	0.0	0.0	0.0
SrO	0.0	0.0	0.0	0.0	0.0
BaO	0.0	0.0	0.0	0.0	0.0
ZnO	0.0	0.0	0.0	0.0	0.0
TiO_2	0.002	0.002	0.002	0.002	0.002
ZrO_2	0.0	0.0	0.0	0.0	0.0
SnO_2	0.05	0.05	0.05	0.05	0.05
Y_2O_3	0.0	0.0	0.0	0.0	0.0
La_2O_3	0.0	0.0	0.0	0.0	0.0
Fe_2O_3	0.002	0.002	0.002	0.002	0.002
P_2O_5	0.0	0.0	0.0	0.0	0.0
SO_3	0.0	0.0	0.0	0.0	0.0
Cl	0.1	0.1	0.1	0.1	0.1
MoO_3	0.001	0.001	0.001	0.001	0.001
B_2O_3 + MgO + CaO	2.4	4.4	1.9	3.9	3.9
Al_2O_3 + Li_2O + Na_2O + K_2O	28.9	26.9	29.4	27.4	27.4
R_2O/Al_2O_3	1.12	1.32	0.89	0.76	1.02
$Al_2O_3/(R_2O + RO)$	0.87	0.74	1.10	1.28	0.96
Na_2O/Li_2O	1.00	1.00	0.80	0.53	0.80
Li_2O/Al_2O_3	0.55	0.65	0.48	0.48	0.55
Q	−0.93	3.07	−4.15	−3.15	−0.15
X	442	381	533	575	472
Y	19	18	19	17	18
Z	35	30	48	59	43
W	336	291	417	467	372
U	7,778	7,605	8,193	8,523	8,020
ρ (g/cm^3)	2.3907	2.3857	2.3873	2.3698	2.3662
Ts (° C.)	N.A.	746.5	948	923	871
$\alpha_{300\text{-}380°\ C.}$ ($\times 10^{-7}$/° C.)	N.A.	N.A.	N.A.	N.A.	N.A.
$10^{2.5}$ dPa · s (° C.)	1,613	1,574	1,637	1,618	1,618.3
E (GPa)	77.4	77.1	78.6	77.7	75.1
CS_K (MPa)	888	739	1,163	982	942
DOL_K (μm)	18	13	20	13	19
CS_{Na} (MPa)	364	296	390	381	408
$CS30_{Na}$ (MPa)	170	119	201	166	180
DOC_{Na} (μm)	81	73	93	73	84
$CTcv_{Na}$ (MPa)	48	33	64	45	54
DOC_{Na}/DOL_K	4.5	5.6	4.6	5.6	4.4
Acid resistance 5 wt % HCl 80° C. 24 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.
Alkali resistance 5 wt % NaOH 80° C. 6 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.
K1c (SEPB) ($MPam^{0.5}$)	N.A.	N.A.	N.A.	N.A.	N.A.
Fracture energy γ	N.A.	N.A.	N.A.	N.A.	N.A.

TABLE 25-continued

Component (mol %)	No. 238	No. 239	No. 240	No. 241	No. 242
SiO_2	68.515	66.515	66.515	65.815	65.815
Al_2O_3	12.63	15.61	15.61	15.63	15.63
B_2O_3	6.0	1.5	2.5	1.7	1.7
Li_2O	7.51	9.51	9.51	7.51	8.51
Na_2O	4.49	6.01	5.01	7.49	7.49
K_2O	0.3	0.3	0.3	1.3	0.3
MgO	0.4	0.4	0.4	0.4	0.4
CaO	0.0	0.0	0.0	0.0	0.0
SrO	0.0	0.0	0.0	0.0	0.0
BaO	0.0	0.0	0.0	0.0	0.0
ZnO	0.0	0.0	0.0	0.0	0.0
TiO_2	0.002	0.002	0.002	0.002	0.002
ZrO_2	0.0	0.0	0.0	0.0	0.0
SnO_2	0.05	0.05	0.05	0.05	0.05
Y_2O_3	0.0	0.0	0.0	0.0	0.0
La_2O_3	0.0	0.0	0.0	0.0	0.0
Fe_2O_3	0.002	0.002	0.002	0.002	0.002
P_2O_5	0.0	0.0	0.0	0.0	0.0
SO_3	0.0	0.0	0.0	0.0	0.0
Cl	0.1	0.1	0.1	0.1	0.1
MoO_3	0.001	0.001	0.001	0.001	0.001
B_2O_3 + MgO + CaO	6.4	1.9	2.9	2.1	2.1
Al_2O_3 + Li_2O + Na_2O + K_2O	24.9	31.4	30.4	31.9	31.9
R_2O/Al_2O_3	0.97	1.01	0.95	1.04	1.04
$Al_2O_3/(R_2O + RO)$	0.99	0.96	1.03	0.94	0.94
Na_2O/Li_2O	0.60	0.63	0.53	1.00	0.88
Li_2O/Al_2O_3	0.59	0.61	0.61	0.48	0.54
Q	2.57	−10.15	−9.65	−10.33	−11.33
X	475	633	654	501	549
Y	16	17	17	19	18
Z	49	58	63	40	45
W	388	500	525	373	415
U	8,186	7,926	8,091	7,816	7,828
ρ (g/cm^3)	2.3369	2.3938	2.3817	2.4033	2.4011
Ts (° C.)	856	N.A.	N.A.	874	N.A.
$\alpha_{300\text{-}380°\ C.}$ (×10^{-7}/° C.)	N.A.	N.A.	N.A.	N.A.	N.A.
$10^{2.5}$ dPa · s (° C.)	1,614	1,588.7	1,584.4	1,598	1,583
E (GPa)	72.5	79	78.3	77.8	78.6
CS_K (MPa)	825	1,104	1,105	1,035	1,051
DOL_K (μm)	16	19	17	25	20
CS_{Na} (MPa)	365	623	493	329	403
$CS30_{Na}$ (MPa)	163	249	249	173	222
DOC_{Na} (μm)	75	80	87	86	89
$CTcv_{Na}$ (MPa)	44	74	72	−51	−66
DOC_{Na}/DOL_K	4.7	4.2	5.1	3.4	4.5
Acid resistance 5 wt % HCl 80° C. 24 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.
Alkali resistance 5 wt % NaOH 80° C. 6 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.
K1c (SEPB) (MPam$^{0.5}$)	N.A.	N.A.	N.A.	N.A.	N.A.
Fracture energy γ	N.A.	N.A.	N.A.	N.A.	N.A.

TABLE 26

Component (mol %)	No. 243	No. 244	No. 245	No. 246	No. 247
SiO_2	65.315	63.815	65.815	66.315	62.255
Al_2O_3	15.63	15.63	15.63	15.63	15.63
B_2O_3	1.7	1.7	1.7	1.7	1.7
Li_2O	8.51	7.51	9.01	9.01	8.01
Na_2O	7.49	7.49	7.49	7.49	7.49
K_2O	1.3	1.8	0.3	1.8	0.8
MgO	0.4	0.4	0.4	0.4	0.4
CaO	0.0	0.0	0.0	0.0	0.0
SrO	0.0	0.0	0.0	0.0	0.0
BaO	0.0	0.0	0.0	0.0	0.0

TABLE 26-continued

ZnO	0.0	0.0	0.0	0.0	0.0
TiO_2	0.002	0.002	0.002	0.002	0.002
ZrO_2	0.0	0.0	0.0	0.0	0.0
SnO_2	0.05	0.05	0.05	0.05	0.05
Y_2O_3	0.0	0.0	0.0	0.0	0.0
La_2O_3	0.0	0.0	0.0	0.0	0.0
Fe_2O_3	0.002	0.002	0.002	0.002	0.002
P_2O_5	0.0	0.0	0.0	0.0	0.0
SO_3	0.0	0.0	0.0	0.0	0.0
Cl	0.1	0.1	0.1	0.1	0.1
MoO_3	0.001	0.001	0.001	0.001	0.001
B_2O_3 + MgO + CaO	2.1	2.1	2.1	2.1	2.1
Al_2O_3 + Li_2O + Na_2O + K_2O	32.9	32.4	32.4	33.9	31.9
R_2O/Al_2O_3	1.11	1.07	1.07	1.17	1.04
$Al_2O_3/(R_2O + RO)$	0.88	0.91	0.91	0.84	0.94
Na_2O/Li_2O	0.88	1.00	0.83	0.83	0.94
Li_2O/Al_2O_3	0.54	0.48	0.58	0.58	0.51
Q	−12.83	−12.83	−12.33	−13.33	−14.39
X	550	504	573	573	530
Y	18	19	18	18	18
Z	45	39	47	47	42
W	415	373	435	436	394
U	7,726	7,612	7,805	7,761	7,511
ρ (g/cm^3)	2.4103	2.4086	2.4044	2.4176	2.402
Ts (° C.)	854.5	N.A.	N.A.	N.A.	875.5
$\alpha_{300\text{-}380°\ C.}$ (×10^{-7}/° C.)	N.A.	N.A.	N.A.	N.A.	77.2
$10^{2.5}$ dPa · s (° C.)	1,573	1,596	1,569	1,553	1,597
E (GPa)	78.5	77.6	78.7	N.A.	78.1
CS_K (MPa)	938	959	1,002	N.A.	1,038
DOL_K (μm)	20	27	18	N.A.	23
CS_{Na} (MPa)	361	359	496	N.A.	376
$CS30_{Na}$ (MPa)	175	142	217	N.A.	198
DOC_{Na} (μm)	79	81	78	N.A.	86
$CTcv_{Na}$ (MPa)	−48	−42	−61	N.A.	−56
DOC_{Na}/DOL_K	4.0	3.0	4.3	N.A.	3.7
Acid resistance 5 wt % HCl 80° C. 24 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	1.1
Alkali resistance 5 wt % NaOH 80° C. 6 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	0.6
K1c (SEPB) (MPam$^{0.5}$)	N.A.	N.A.	N.A.	N.A.	0.8
Fracture energy γ	N.A.	N.A.	N.A.	N.A.	8.194622

Component (mol %)	No. 248	No. 249	No. 250	No. 251	No. 252
SiO_2	63.255	62.755	63.755	62.255	63.255
Al_2O_3	15.63	18.51	18.51	18.01	18.01
B_2O_3	1.7	0.0	0.0	0.0	0.0
Li_2O	7.51	8.65	7.65	8.65	7.65
Na_2O	7.49	8.63	8.63	8.63	8.63
K_2O	0.8	0.8	0.8	0.8	0.8
MgO	0.4	1.0	1.0	1.0	1.0
CaO	0.0	0.0	0.0	0.0	0.0
SrO	0.0	0.0	0.0	0.0	0.0
BaO	0.0	0.0	0.0	0.0	0.0
ZnO	0.0	0.0	0.0	0.0	0.0
TiO_2	0.002	0.002	0.002	0.002	0.002
ZrO_2	0.0	0.0	0.0	0.0	0.0
SnO_2	0.05	0.05	0.05	0.05	0.05
Y_2O_3	0.0	0.0	0.0	0.0	0.0
La_2O_3	0.0	0.0	0.0	0.0	0.0
Fe_2O_3	0.002	0.002	0.002	0.002	0.002
P_2O_5	0.0	0.0	0.0	0.0	0.0
SO_3	0.0	0.0	0.0	0.0	0.0
Cl	0.1	0.1	0.1	0.1	0.1
MoO_3	0.001	0.001	0.001	0.001	0.001
B_2O_3 + MgO + CaO	2.1	1.0	1.0	1.0	1.0
Al_2O_3 + Li_2O + Na_2O + K_2O	31.4	36.6	35.6	36.1	35.1
R_2O/Al_2O_3	1.01	0.98	0.92	1.00	0.95
$Al_2O_3/(R_2O + RO)$	0.96	0.97	1.02	0.94	1.00
Na_2O/Li_2O	1.00	1.00	1.13	1.00	1.13
Li_2O/Al_2O_3	0.48	0.47	0.41	0.48	0.42
Q	−12.39	−23.82	−20.82	−22.82	−19.82

TABLE 26-continued

X	504	616	566	603	553
Y	18	19	20	19	19
Z	39	44	40	43	38
W	373	448	406	439	397
U	7,621	7,872	8,005	7,738	7,872
ρ (g/cm^3)	2.3984	2.4372	2.4344	2.435	2.4313
Ts (° C.)	893.5	N.A.	932	N.A.	N.A.
$\alpha_{300\text{-}380^\circ C.}$ (×10^{-7}/° C.)	N.A.	N.A.	N.A.	N.A.	N.A.
$10^{2.5}$ dPa · s (° C.)	1,608	1,555	1,584	1,560	1,584
E (GPa)	77.4	81.6	81.2	81.5	81
CS_K (MPa)	1,101	1,354	1,354	1,312	1,349
DOL_K (μm)	25	23	24	23	25
CS_{Na} (MPa)	345	462	425	470	387
$CS30_{Na}$ (MPa)	177	220	223	240	192
DOC_{Na} (μm)	94	81	89	86	87
$CTcv_{Na}$ (MPa)	−56	67	62	70	63
DOC_{Na}/DOL_K	3.8	3.5	3.7	3.7	3.5
Acid resistance 5 wt % HCl 80° C. 24 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.
Alkali resistance 5 wt % NaOH 80° C. 6 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.
K1c (SEPB) (MPam$^{0.5}$)	N.A.	N.A.	N.A.	N.A.	N.A.
Fracture energy γ	N.A.	N.A.	N.A.	N.A.	N.A.

TABLE 27

Component (mol %)	No. 253	No. 254	No. 255	No. 256	No. 257
SiO_2	62.255	62.255	62.055	61.855	61.255
Al_2O_3	18.51	18.51	19.01	19.01	18.51
B_2O_3	0.0	0.0	0.0	0.0	0.0
Li_2O	8.65	7.65	9.15	8.15	8.65
Na_2O	7.63	7.63	8.63	8.63	8.63
K_2O	0.8	0.8	0.8	0.8	0.8
MgO	1.0	1.0	1.0	1.0	0.8
CaO	0.0	0.0	0.0	0.0	0.0
SrO	0.0	0.0	0.0	0.0	0.0
BaO	0.0	0.0	0.0	0.0	0.0
ZnO	0.0	0.0	0.0	0.0	0.0
TiO_2	0.002	0.002	0.002	0.002	0.002
ZrO_2	0.0	0.0	0.0	0.0	0.0
SnO_2	0.05	0.05	0.05	0.05	0.05
Y_2O_3	0.0	0.0	0.0	0.0	0.0
La_2O_3	0.0	0.0	0.0	0.0	0.0
Fe_2O_3	0.002	0.002	0.002	0.002	0.002
P_2O_5	1.0	1.0	0.0	0.0	0.2
SO_3	0.0	0.0	0.0	0.0	0.0
Cl	0.1	0.1	0.1	0.1	0.1
MoO_3	0.001	0.001	0.001	0.001	0.001
B_2O_3 + MgO + CaO	1.0	1.0	1.0	1.0	0.8
$Al_2O_3 + Li_2O + Na_2O + K_2O$	35.6	34.6	37.6	36.6	36.6
R_2O/Al_2O_3	0.92	0.87	0.98	0.92	0.98
$Al_2O_3/(R_2O + RO)$	1.02	1.08	0.97	1.02	0.98
Na_2O/Li_2O	0.88	1.00	0.94	1.06	1.00
Li_2O/Al_2O_3	0.47	0.41	0.48	0.43	0.47
Q	−21.62	−19.62	−27.02	−25.22	−25.08
X	641	592	655	606	618
Y	18	19	19	19	19
Z	50	45	48	43	45
W	477	435	477	436	447
U	7,859	7,905	7,878	7,906	7,710
ρ (g/cm^3)	2.4271	2.4241	2.4411	2.4384	2.4341
Ts (° C.)	N.A.	939	N.A.	923	N.A.
$\alpha_{300\text{-}380^\circ C.}$ (×10^{-7}/° C.)	N.A.	N.A.	N.A.	N.A.	N.A.
$10^{2.5}$ dPa · s (° C.)	1,559	1,582	1,539	1,558	1,559
E (GPa)	80.9	80.5	82.27	81.77	80.6
CS_K (MPa)	1,278	1,269	1,359	1,388	1,321
DOL_K (μm)	23	23	21	23	24

TABLE 27-continued

CS_{Na} (MPa)	478	409	471	409	347
$CS30_{Na}$ (MPa)	230	204	238	219	211
DOC_{Na} (μm)	85	84	84	89	99
$CTcv_{Na}$ (MPa)	66	59	69	65	67
DOC_{Na}/DOL_K	3.7	3.7	4.0	3.9	4.2
Acid resistance 5 wt % HCl 80° C. 24 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.
Alkali resistance 5 wt % NaOH 80° C. 6 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.
K1c (SEPB) ($MPam^{0.5}$)	N.A.	N.A.	N.A.	N.A.	N.A.
Fracture energy γ	N.A.	N.A.	N.A.	N.A.	N.A.
Component (mol %)	No. 258	No. 259	No. 260	No. 261	No. 262
SiO_2	60.255	61.255	61.755	67.615	67.035
Al_2O_3	18.51	18.51	18.51	18.51	18.51
B_2O_3	0.0	0.0	0.0	0.0	0.0
Li_2O	8.65	8.65	8.65	8.65	8.65
Na_2O	8.63	8.63	8.63	8.63	8.63
K_2O	0.8	0.8	0.8	0.8	0.8
MgO	0.6	1.0	1.0	1.0	1.0
CaO	0.0	0.0	0.0	0.0	0.0
SrO	0.0	0.0	0.0	0.0	0.0
BaO	0.0	0.0	0.0	0.0	0.0
ZnO	0.0	0.0	0.0	0.0	0.0
TiO_2	0.002	0.002	0.002	0.002	0.002
ZrO_2	0.0	0.0	0.0	1.0	2.0
SnO_2	0.05	0.05	0.05	0.05	0.05
Y_2O_3	0.0	0.0	0.0	0.0	0.0
La_2O_3	0.0	0.0	0.0	0.0	0.0
Fe_2O_3	0.002	0.002	0.002	0.002	0.002
P_2O_5	0.4	0.2	0.4	0.0	0.0
SO_3	0.0	0.0	0.0	0.0	0.0
Cl	0.1	0.1	0.1	0.1	0.1
MoO_3	0.001	0.001	0.001	0.001	0.001
$B_2O_3 + MgO + CaO$	0.6	1.0	1.0	1.0	1.0
$Al_2O_3 + Li_2O + Na_2O + K_2O$	36.6	36.6	36.6	36.6	36.6
R_2O/Al_2O_3	0.98	0.98	0.98	0.98	0.98
$Al_2O_3/(R_2O + RO)$	0.99	0.97	0.97	0.97	0.97
Na_2O/Li_2O	1.00	1.00	1.00	1.00	1.00
Li_2O/Al_2O_3	0.47	0.47	0.47	0.47	0.47
Q	−25.84	−25.08	−24.34	−18.96	−19.54
X	620	618	617	609	609
Y	19	19	19	20	20
Z	45	44	44	45	45
W	447	448	448	448	448
U	7,592	7,733	7,768	8,297	8,246
ρ (g/cm^3)	2.4313	2.4358	2.4345	2.4658	2.4942
Ts (° C.)	N.A.	N.A.	N.A.	N.A.	N.A.
$\alpha_{300\text{-}380°\ C.}$ ($\times 10^{-7}$/° C.)	N.A.	N.A.	N.A.	N.A.	N.A.
$10^{2.5}$ dPa · s (° C.)	1,565	1,553	1,555	1,534	1,508
E (GPa)	80.6	81.2	81.0	82.2	83.0
CS_K (MPa)	1,309	1,320	1,311	1,436	1,509
DOL_K (μm)	25	23	23	20	18
CS_{Na} (MPa)	371	346	329	395	380
$CS30_{Na}$ (MPa)	225	217	209	223	232
DOC_{Na} (μm)	99	104	105	90	100
$CTcv_{Na}$ (MPa)	71	75	71	70	75
DOC_{Na}/DOL_K	3.9	4.5	4.5	4.4	5.5
Acid resistance 5 wt % HCl 80° C. 24 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.
Alkali resistance 5 wt % NaOH 80° C. 6 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.
K1c (SEPB) ($MPam^{0.5}$)	N.A.	N.A.	N.A.	N.A.	N.A.
Fracture energy γ	N.A.	N.A.	N.A.	N.A.	N.A.

TABLE 28

Component (mol %)	No. 263	No. 264	No. 265	No. 266	No. 267
SiO_2	66.022	65.853	65.784	65.765	65.794
Al_2O_3	18.51	18.51	10.97	12.50	14.05
B_2O_3	0.0	0.0	0.5	0.9	1.3
Li_2O	8.65	8.65	7.95	7.97	7.99
Na_2O	8.63	8.63	7.99	7.82	7.66
K_2O	0.8	0.8	2.5	1.9	1.4
MgO	1.0	1.0	2.3	1.7	1.1
CaO	0.0	0.0	0.0	0.0	0.0
SrO	0.0	0.0	0.0	0.0	0.0
BaO	0.0	0.0	0.0	0.0	0.0
ZnO	0.0	0.0	0.0	0.0	0.0
TiO_2	0.002	0.002	0.002	0.002	0.002
ZrO_2	0.0	0.0	0.0	0.0	0.0
SnO_2	0.05	0.05	0.07	0.07	0.06
Y_2O_3	0.0	0.0	0.0	0.0	0.0
La_2O_3	1.0	0.5	0.0	0.0	0.0
Fe_2O_3	0.002	0.002	0.002	0.002	0.002
P_2O_5	0.0	0.0	0.0	0.0	0.0
SO_3	0.0	0.0	0.0	0.0	0.0
Cl	0.1	0.1	0.1	0.1	0.1
MoO_3	0.001	0.001	0.001	0.001	0.001
B_2O_3 + MgO + CaO	1.0	1.0	2.8	2.6	2.4
Al_2O_3 + Li_2O + Na_2O + K_2O	36.6	36.6	29.4	30.2	31.1
R_2O/Al_2O_3	0.98	0.98	1.68	1.42	1.21
$Al_2O_3/(R_2O + RO)$	0.97	0.97	0.53	0.64	0.77
Na_2O/Li_2O	1.00	1.00	1.01	0.98	0.96
Li_2O/Al_2O_3	0.47	0.47	0.72	0.64	0.57
Q	−20.55	−20.72	1.99	−2.21	−6.53
X	611	611	388	433	478
Y	20	20	16	17	18
Z	45	45	24	30	36
W	448	448	300	331	362
U	8,157	8,143	6,951	7,241	7,531
ρ (g/cm^3)	2.5256	2.4793	2.4261	2.4213	2.4136
Ts (° C.)	871	887	729	757	N.A.
$\alpha_{300\text{-}380°\ C.}$ ($\times 10^{-7}$/° C.)	N.A.	N.A.	88.3	84.5	80.9
$10^{2.5}$ dPa · s (° C.)	1,499	1,526	1,501	1,538	1,574
E (GPa)	83.9	82.4	78.2	78.4	78.6
CS_K (MPa)	1,454	1,394	657	751	870
DOL_K (μm)	17	19	18	18	19
CS_{Na} (MPa)	336	361	119	161	244
$CS30_{Na}$ (MPa)	207	219	68	91	133
DOC_{Na} (μm)	102	98	93	90	88
$CTcv_{Na}$ (MPa)	63	68	19	27	38
DOC_{Na}/DOL_K	6.1	5.2	5.1	5.0	4.7
Acid resistance 5 wt % HCl 80° C. 24 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.
Alkali resistance 5 wt % NaOH 80° C. 6 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.
K1c (SEPB) (MPam$^{0.5}$)	0.88	N.A.	N.A.	N.A.	N.A.
Fracture energy γ	9.232567	N.A.	N.A.	N.A.	N.A.

Component (mol %)	No. 268	No. 269	No. 270	No. 271	No. 272
SiO_2	65.763	65.752	65.741	66.605	63.995
Al_2O_3	15.31	13.65	14.31	14.97	15.50
B_2O_3	1.6	0.4	0.9	1.3	1.6
Li_2O	8.01	2.03	4.03	6.02	7.61
Na_2O	7.52	14.56	12.20	9.84	7.96
K_2O	0.9	0.2	0.4	0.6	0.8
MgO	0.5	3.0	2.1	1.3	0.6
CaO	0.0	0.0	0.0	0.0	0.0
SrO	0.0	0.0	0.0	0.0	0.0
BaO	0.0	0.0	0.0	0.0	0.0
ZnO	0.0	0.0	0.0	0.0	0.0
TiO_2	0.002	0.002	0.002	0.002	0.002
ZrO_2	0.0	0.0	0.0	0.0	0.0
SnO_2	0.05	0.13	0.10	0.08	0.06
Y_2O_3	0.0	0.0	0.0	0.0	0.0

TABLE 28-continued

La_2O_3	0.0	0.0	0.0	0.0	0.0
Fe_2O_3	0.002	0.002	0.002	0.002	0.002
P_2O_5	0.0	0.0	0.0	0.0	0.0
SO_3	0.0	0.0	0.0	0.0	0.0
Cl	0.1	0	0.1	0.1	0.1
MoO_3	0.001	0.001	0.001	0.001	0.001
B_2O_3 + MgO + CaO	2.1	3.4	3.0	2.6	2.2
Al_2O_3 + Li_2O + Na_2O + K_2O	31.7	30.4	30.9	31.4	31.9
R_2O/Al_2O_3	1.07	1.23	1.16	1.10	1.06
$Al_2O_3/(R_2O + RO)$	0.90	0.69	0.76	0.84	0.91
Na_2O/Li_2O	0.94	7.17	3.03	1.63	1.05
Li_2O/Al_2O_3	0.52	0.15	0.28	0.40	0.49
Q	−9.97	−1.70	−4.85	−7.00	−12.07
X	516	13	184	353	494
Y	19	23	21	20	19
Z	41	−36	−10	16	37
W	388	−87	73	234	362
U	7,754	7,443	7,569	7,774	7,638
ρ (g/cm^3)	2.4047	2.4439	2.4333	2.419	2.4058
Ts (° C.)	863	869	852	852	N.A.
$\alpha_{300\text{-}380°\ C.}$ (×10^{-7}/° C.)	77.2	87.2	84.4	80.7	78
$10^{2.5}$ dPa · s (° C.)	1,595	1,618	1,607	1,606	1,597
E (GPa)	78.0	74.4	77.4	76.8	77.8
CS_K (MPa)	1,011	1,147	1,110	1,071	1,055
DOL_K (μm)	20	28	24	22	22
CS_{Na} (MPa)	271	47	102	188	247
$CS30_{Na}$ (MPa)	165	32	66	120	160
DOC_{Na} (μm)	100	117	108	107	108
$CTcv_{Na}$ (MPa)	52	13	25	42	56
DOC_{Na}/DOL_K	4.9	4.2	4.6	4.9	5.0
Acid resistance 5 wt % HCl 80° C. 24 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.
Alkali resistance 5 wt % NaOH 80° C. 6 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.
K1c (SEPB) (MPam$^{0.5}$)	N.A.	N.A.	N.A.	N.A.	N.A.
Fracture energy γ	N.A.	N.A.	N.A.	N.A.	N.A.

TABLE 29

Component (mol %)	No. 273	No. 274	No. 275	No. 276	No. 277
SiO_2	63.495	63.995	63.995	63.995	68.200
Al_2O_3	15.63	15.63	15.63	15.63	9.50
B_2O_3	1.7	1.7	1.7	1.7	0.1
Li_2O	8.01	8.01	8.01	8.01	8.00
Na_2O	7.49	7.49	7.49	7.49	8.16
K_2O	0.8	0.8	0.8	0.8	3.0
MgO	0.4	0.4	0.4	0.4	3.0
CaO	0.0	0.0	0.0	0.0	0.0
SrO	0.0	0.0	0.0	0.0	0.0
BaO	0.0	0.0	0.0	0.0	0.0
ZnO	0.0	0.0	0.0	0.0	0.0
TiO_2	0.002	0.002	0.002	0.002	0.000
ZrO_2	0.0	0.0	0.0	0.0	0.0
SnO_2	0.07	0.10	0.11	0.12	0.04
Y_2O_3	0.0	0.0	0.0	0.0	0.0
La_2O_3	0.0	0.0	0.0	0.0	0.0
Fe_2O_3	0.002	0.002	0.002	0.002	0.01
P_2O_5	0.0	0.0	0.0	0.0	0.0
SO_3	0.0	0.0	0.0	0.0	0.0
Cl	0.1	0.1	0.1	0.1	0.01
MoO_3	0.002	0.003	0.004	0.005	0
B_2O_3 + MgO + CaO	2.1	2.1	2.1	2.1	3.1
Al_2O_3 + Li_2O + Na_2O + K_2O	31.9	31.9	31.9	31.9	28.7
R_2O/Al_2O_3	1.04	1.04	1.04	1.04	2.02
$Al_2O_3/(R_2O + RO)$	0.94	0.94	0.94	0.94	0.43
Na_2O/Li_2O	0.94	0.94	0.94	0.94	1.02
Li_2O/Al_2O_3	0.51	0.51	0.51	0.51	0.84
Q	−13.15	−12.65	−12.65	−12.65	8.36

TABLE 29-continued

X	528	528	528	528	344
Y	18	18	18	18	16
Z	42	42	42	42	19
W	394	394	394	394	274
U	7,619	7,663	7,663	7,663	6,896
ρ (g/cm^3)	2.403	2.4039	2.4047	2.4043	2.4264
Ts (° C.)	874	874	874	874	685
$\alpha_{300\text{-}380^\circ C.}$ ($\times 10^{-7}$/° C.)	77	77	77	77	95.9
$10^{2.5}$ dPa · s (° C.)	1,591	1,591	1,591	1,591	1,435
E (GPa)	78	78	78	78	77.4
CS_K (MPa)	1,057	1,055	1,072	1,059	473
DOL_K (μm)	22	22	22	22	20
CS_{Na} (MPa)	304	287	258	299	175
$CS30_{Na}$ (MPa)	183	181	174	185	46
DOC_{Na} (μm)	98	104	115	101	62
$CTcv_{Na}$ (MPa)	57	61	62	61	13
DOC_{Na}/DOL_K	4.4	4.7	5.2	4.6	3.1
Acid resistance 5 wt % HCl 80° C. 24 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	0.0
Alkali resistance 5 wt % NaOH 80° C. 6 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	0.6
K1c (SEPB) (MPam$^{0.5}$)	N.A.	N.A.	N.A.	N.A.	0.79
Fracture energy γ	N.A.	N.A.	N.A.	N.A.	8.06

Component (mol %)	No. 278	No. 279	No. 280	No. 281	No. 282
SiO_2	65.730	65.729	65.730	66.284	66.215
Al_2O_3	15.63	15.63	15.63	12.49	13.54
B_2O_3	1.7	1.7	1.7	0.8	1.1
Li_2O	8.01	8.01	8.01	2.02	4.02
Na_2O	7.57	7.57	7.57	13.24	11.33
K_2O	0.8	0.8	0.8	1.2	1.1
MgO	0.4	0.4	0.4	3.7	2.6
CaO	0.0	0.0	0.0	0.0	0.0
SrO	0.0	0.0	0.0	0.0	0.0
BaO	0.0	0.0	0.0	0.0	0.0
ZnO	0.0	0.0	0.0	0.0	0.0
TiO_2	0.003	0.003	0.001	0.002	0.000
ZrO_2	0.0	0.0	0.0	0.0	0.0
SnO_2	0.05	0.05	0.05	0.13	0.10
Y_2O_3	0.0	0.0	0.0	0.0	0.0
La_2O_3	0.0	0.0	0.0	0.0	0.0
Fe_2O_3	0.001	0.001	0.001	0.002	0.01
P_2O_5	0.0	0.0	0.0	0.0	0.0
SO_3	0.0	0.0	0.0	0.0	0.0
Cl	0.1	0.1	0.1	0.1	0.01
MoO_3	0.002	0.003	0.004	0.005	0.0
B_2O_3 + MgO + CaO	2.1	2.1	2.1	4.5	3.7
Al_2O_3 + Li_2O + Na_2O + K_2O	32.0	32.0	32.0	29.0	30.0
R_2O/Al_2O_3	1.05	1.05	1.05	1.32	1.21
$Al_2O_3/(R_2O$ + RO)	0.93	0.93	0.93	0.62	0.71
Na_2O/Li_2O	0.95	0.95	0.95	6.55	2.82
Li_2O/Al_2O_3	0.51	0.51	0.51	0.16	0.30
Q	−11.04	−11.04	−11.04	2.89	−1.60
X	523	523	523	11	182
Y	19	19	19	21	20
Z	42	42	42	−33	−8
W	392	392	392	−71	84
U	7,809	7,809	7,809	7,431	7,569
ρ (g/cm^3)	2.402	2.4028	2.4046	2.4421	2.4316
Ts (° C.)	864	860.5	864	841.5	835
$\alpha_{300\text{-}380^\circ C.}$ ($\times 10^{-7}$/° C.)	77.4	77.2	77.3	88.9	84.9
$10^{2.5}$ dPa · s (° C.)	1,594.5	1,591.9	1,597.7	1,590	1,598
E (GPa)	N.A.	N.A.	N.A.	74.4	76.3
CS_K (MPa)	1,014	978	969	1,018	1,044
DOL_K (μm)	22	22	22	27	24
CS_{Na} (MPa)	278	251	270	25	102
$CS30_{Na}$ (MPa)	176	161	171	21	61
DOC_{Na} (μm)	104	106	105	129	98
$CTcv_{Na}$ (MPa)	62	57	57	10	20
DOC_{Na}/DOL_K	4.6	4.9	4.8	4.8	4.1

TABLE 29-continued

Acid resistance 5 wt % HCl 80° C. 24 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.
Alkali resistance 5 wt % NaOH 80° C. 6 h (mg/cm^2)	N.A.	N.A.	N.A.	N.A.	N.A.
K1c (SEPB) ($MPam^{0.5}$)	N.A.	N.A.	N.A.	N.A.	N.A.
Fracture energy γ	N.A.	N.A.	N.A.	N.A.	N.A.

TABLE 30

Component (mol %)	No. 283	No. 284	No. 285
SiO_2	65.972	65.852	65.852
Al_2O_3	14.58	15.42	15.63
B_2O_3	1.4	1.6	1.7
Li_2O	6.02	7.61	8.01
Na_2O	9.41	7.87	7.49
K_2O	0.9	0.8	0.8
MgO	1.5	0.6	0.4
CaO	0.0	0.0	0.0
SrO	0.0	0.0	0.0
BaO	0.0	0.0	0.0
ZnO	0.0	0.0	0.0
TiO_2	0.002	0.002	0.001
Zro_2	0.0	0.0	0.0
SnO_2	0.08	0.06	0.1
Y_2O_3	0.0	0.0	0.0
La_2O_3	0.0	0.0	0.0
Fe_2O_3	0.002	0.002	0.001
P_2O_5	0.0	0.0	0.0
SO_3	0.0	0.0	0.0
Cl	0.1	0.1	0.1
MoO_3	0.002	0.003	0.004
B_2O_3 + MgO + CaO	2.90	2.26	2.10
$Al_2O_3 + Li_2O + Na_2O + K_2O$	31.0	31.7	31.9
R_2O/Al_2O_3	1.12	1.06	1.04
$Al_2O_3/(R_2O + RO)$	0.82	0.91	0.94
Na_2O/Li_2O	1.56	1.03	0.94
Li_2O/Al_2O_3	0.41	0.49	0.51
Q	−6.26	−9.91	−10.79
X	354	491	525
Y	20	19	19
Z	17	37	42
W	239	363	394
U	7,692	7,796	7,825
ρ (g/cm^3)	2.4181	2.4055	2.4041
Ts (° C.)	841.5	866	867.5
$\alpha_{300\text{-}380° C.}$ ($\times 10^{-7}$/° C.)	81.6	77.6	77.4
$10^{2.5}$ dPa's (° C.)	1,602	1,599	1,596
E (GPa)	77.1	77.5	N.A.
CS_K (MPa)	1,035	1,054	1,006
DOL_K (μm)	22	21	21
CS_{Na} (MPa)	182	264	246
$CS30_{Na}$ (MPa)	115	164	159
DOC_{Na} (μm)	105	102	108
$CTcv_{Na}$ (MPa)	39	55	58
DOC_{Na}/DOL_K	4.8	4.7	5.1
Acid resistance 5 wt % HCl 80° C. 24 h (mg/cm^2)	N.A.	N.A.	N.A.
Alkali resistance 5 wt % NaOH 80° C. 6 h (mg/cm^2)	N.A.	N.A.	N.A.
K1c (SEPB) ($MPam^{0.5}$)	N.A.	N.A.	N.A.
Fracture energy γ	N.A.	N.A.	N.A.

[0176] Samples in the tables were each produced as described below. First, glass raw materials were blended so as to give a glass composition shown in the table, and were melted at 1, 600° C. for 21 hours with a platinum pot. Subsequently, the resultant molten glass was poured out on a carbon sheet to be formed into a flat sheet shape, and was then cooled in a temperature region of from an annealing point to a strain point at a rate of 3° C./min. Thus, a glass sheet (glass sheet to be tempered) was obtained. The surface of the resultant glass sheet was optically polished so as to give a sheet thickness of 1.5 mm, and was then evaluated for various characteristics.

[0177] The density (ρ) is a value measured by a well-known Archimedes method.

[0178] The softening point (Ts) is a value measured based on a method of ASTM C338.

[0179] The thermal expansion coefficient (@30-380° C.) at from 30° C. to 380° C. is a value measured for an average thermal expansion coefficient with a dilatometer.

[0180] The temperature ($10^{2.5}$ dPa·s) at a viscosity at high temperature of $10^{2.5}$ dPa·s is a value measured by a platinum sphere pull up method.

[0181] The Young's modulus (E) is a value calculated by a method in conformity with JIS R 1602-1995 "Testing methods for elastic modulus of fine ceramics."

[0182] Subsequently, each of the untempered glass sheets (glass sheets to be tempered) was subjected to ion exchange treatment by being immersed in a KNO_3 molten salt at 430° C. for 4 hours. Thus, a tempered glass sheet having a compressive stress layer in a surface thereof was obtained. After that, the glass surface was washed, and the compressive stress value (CSK) of the compressive stress layer on the outermost surface and the depth of layer (DOL_K) thereof were calculated based on the number of interference fringes observed with a surface stress meter FSM-6000 (manufactured by Orihara Industrial Co., Ltd.) and intervals therebetween. Herein, the DOL_K is the depth of the compressive stress layer obtained through ion exchange with the KNO_3 molten salt.

[0183] In addition, each of the untempered glass sheets (glass sheets to be tempered) was subjected to ion exchange treatment by being immersed in a $NaNO_3$ molten salt at 380° C. for 1 hour. Thus, a tempered glass sheet was obtained. After that, the glass surface was washed, and the compressive stress value (CS_{Na}) of a compressive stress layer on the outermost surface, the compressive stress value (CS30Na) thereof at a depth of 30 μm, the depth of compression (DOC_{Na}) thereof, and the internal tensile stress value ($CTcv_{Na}$) thereof were calculated from a retardation distribution curve observed with a scattered light photoelastic stress meter SLP-2000 (manufactured by Orihara Industrial Co., Ltd.). Herein, the DOC_{Na} is the depth of the compressive stress layer obtained through ion exchange with the $NaNO_3$ molten salt, and is a depth at which the stress value becomes zero.

[0184] In an acid resistance test, acid resistance was evaluated as described below. A glass sample having been

subjected to mirror polishing treatment on both sides so as to give dimensions of 50 mm×10 mm×1.0 mm was used as a measurement sample. The sample was sufficiently washed with a neutral detergent and pure water, and was then immersed in a 5 mass % HCl aqueous solution warmed to 80° C. for 24 hours. A mass loss (mg/cm^2) per unit surface area before and after the immersion was calculated.

[0185] In an alkali resistance test, alkali resistance was evaluated as described below. A glass sample having been subjected to mirror polishing treatment on both sides so as to give dimensions of 50 mm×10 mm×1.0 mm was used as a measurement sample. The sample was sufficiently washed with a neutral detergent and pure water, and was then immersed in a 5 mass % NaOH aqueous solution warmed to 80° C. for 6 hours. A mass loss (mg/cm^2) per unit surface area before and after the immersion was calculated.

[0186] The fracture toughness (K1c) is a value measured by a SEPB method based on JIS R 1607 "Testing methods for fracture toughness of fine ceramics." The fracture toughness value of each of the samples was determined as an average for 3 points.

[0187] As apparent from Tables 1 to 30, each of the tempered glass sheets of Samples Nos. 001 to 102 and Nos. 104 to 285 had a proper content of $[B_2O_3]+[MgO]+[CaO]$ and a proper molar ratio $([Li_2O]+[Na_2O]+[K_2O])/[Al_2O_3]$, and hence had a compressive stress value (CS_{Na}) of the compressive stress layer on the outermost surface and a compressive stress value ($CS30_{Na}$) thereof at a depth of 30 μm from the outermost surface as high as 202 MPa or more and 41 MPa or more, respectively, when having been subjected to ion exchange treatment with $NaNO_3$. Accordingly, it is conceived that a stress profile having an inflection point as shown in FIG. **3** is easily made, and each of the tempered glass sheets is less liable to be broken than that of Sample No. 103 serving as Comparative Example at the time of dropping.

[0188] Further, when the glass sheet (glass sheet to be tempered) according to No. 071 was immersed in a $NaNO_3$ molten salt at 380° C. for 4.5 hours, and was then immersed in a KNO_3 molten salt at 430° C. for 30 minutes, it was recognized that the compressive stress value CS of the compressive stress layer on the outermost surface and the compressive stress value CS30 thereof at a depth of 30 μm from the outermost surface were 768 MPa and 148 MPa, respectively, and were further improved.

[0189] In addition, when the glass sheet (glass sheet to be tempered) according to No. 106 was immersed in a $NaNO_3$ molten salt at 380° C. for 2 hours, and was then immersed in a 92.5 mass % KNO_3 and 7.5 mass % $NaNO_3$ mixed molten salt at 410° C. for 24 minutes, it was recognized that the compressive stress value CS of the compressive stress layer on the outermost surface and the compressive stress value CS30 thereof at a depth of 30 μm from the outermost surface were 873 MPa and 154 MPa, respectively, and were further improved.

[0190] In addition, when the glass sheet (glass sheet to be tempered) according to No. 247 was immersed in a $NaNO_3$ molten salt at 380° C. for 77 minutes, and was then immersed in a 92.5 mass % KNO_3 and 7.5 mass % $NaNO_3$ mixed molten salt at 410° C. for 25 minutes, it was recognized that the compressive stress value CS of the compressive stress layer on the outermost surface and the compressive stress value CS30 thereof at a depth of 30 μm from the outermost surface were 878 MPa and 167 MPa, respectively, and were further improved.

EXAMPLE 2

[0191] An untempered glass sheet (glass sheet to be tempered) having the same composition as that of Sample No. 071 of Example 1 and having a thickness of 0.7 mm was immersed in a $NaNO_3$ molten salt at 380° C. for 540 minutes, and was then immersed in a KNO_3 molten salt at 430° C. for a time period shown in Table 31. Thus, a tempered glass sheet was obtained.

[0192] Further, the resultant tempered glass sheet was measured for its stress profile with a scattered light photoelastic stress meter SLP-2000 (manufactured by Orihara Industrial Co., Ltd.) and a surface stress meter FSM-6000 (manufactured by Orihara Industrial Co., Ltd.). FIG. **4** is a graph showing the general view of stress profiles of Examples 2-1 to 2-3, and FIG. **5** is a graph showing low compressive stress regions in the stress profiles of FIG. **4** in an enlarged manner. The stress profile of the tempered glass sheet on one of main surfaces thereof is shown in each of FIG. **4** and FIG. **5**, but a similar stress profile was observed also on the other surface thereof.

[0193] The tempering conditions and glass characteristics of Examples 2-1 to 2-3 are shown in Table 31. In the table, the term "SPP-4PB" means abraded four-point bending strength.

TABLE 31

Example number		2-1	2-2	2-3
	Thickness (mm)	0.7	0.7	0.7
First ion exchange	Molten salt for tempering	$NaNO_3$	$NaNO_3$	$NaNO_3$
	Temperature of molten salt (° C.)	380	380	380
	Tempering time period (min)	540	540	540
Second ion exchange	Molten salt for tempering	KNO_3	KNO_3	KNO_3
	Temperature of molten salt (C)	430	430	430
	Tempering time period (min)	15	30	45
	CS (MPa)	853	815	772
	De (μm)	3.4	5.1	5.9
	DOC (μm)	125	132	134
	CT (MPa)	94	91	89
	CS30 (MPa)	189	158	148
	CS50 (MPa)	121	114	111
	SPP-4PB (MPa)	227	206	199

[0194] For each of the samples (Examples 2-1 to 2-3), the glass surface was washed, and the compressive stress value (CS) of a compressive stress layer on the outermost surface and the depth De of an inflection point were calculated with a surface stress meter FSM-6000 (manufactured by Orihara Industrial Co., Ltd.). In the table, the value of the depth (De) of the inflection point represents the value of the diffusion depth DOL of a K ion obtained with FSM-6000 (De=DOL). In such a tempered glass sheet as those of Examples 2-1 to 2-3 of the present invention, that is, a tempered glass sheet in which a Li ion in the glass and a Na ion in the molten salt have been exchanged (K ion has not been exchanged) through first ion exchange, and a Na ion in the glass and a K ion in the molten salt have been exchanged through

second ion exchange, the depth De of the inflection point "e" roughly coincides with the diffusion depth DOL of a K ion.

[0195] In addition, the compressive stress values (CS30 and CS50) of the compressive stress layer at depths of 30 μm and 50 μm, the depth of compression (DOC) thereof, and the internal tensile stress value (CT) thereof were calculated from a retardation distribution curve observed with a scattered light photoelastic stress meter SLP-2000 (manufactured by Orihara Industrial Co., Ltd.).

[0196] The abraded four-point bending strength was measured by the following procedure. First, the glass was abraded by the following procedure. The tempered glass sheet having been processed into a size of 50 mm×50 mm and a thickness shown in Table 31 was fixed to a SUS plate having a thickness of 1.5 mm under the state in which the tempered glass sheet was turned vertically, and the tip of a pendular arm was caused to collide with the glass sheet through P180 grid sandpaper to abrade the glass sheet. The tip of the arm is an iron-made cylinder of ϕ5 mm, and the arm has a weight of 550 g. The height from which the arm was swung down was set to 5 mm from a collision point. Next, the abraded sample was measured for strength by being subjected to a four-point bending test according to JIS R 1601 (1995).

[0197] As apparent from Table 31 and FIG. **4** and FIG. **5**, in each of the tempered glass sheets of Examples 2-1 to 2-3 had a compressive stress value (CS) of the compressive stress layer on the outermost surface and a compressive stress value (CS30) thereof at a depth of 30 μm from the outermost surface as high as 815 MPa or more and 148 MPa or more, respectively. In addition, the abraded four-point bending strength is as high as 199 MPa or more, and hence it is conceived that each of the tempered glass sheets is less liable to be broken at the time of dropping.

EXAMPLE 3

[0198] An untempered glass sheet (glass sheet to be tempered) having the same composition as that of each of Samples No. 106 and No. 247 of Example 1 and having a thickness of 0.7 mm was immersed in a $NaNO_3$ molten salt at 380° C. for a time period shown in Table 32, and was then immersed in a KNO_3 molten salt at 430° C. for a time period shown in Table 32. Thus, a tempered glass sheet was obtained.

[0199] Further, the resultant tempered glass sheet was measured for its stress profile by the same method as in Example 2. FIG. **6** is a graph showing the general view of stress profiles of Examples 3-1 and 3-2, and FIG. **7** is a graph showing low compressive stress regions in the stress profiles of FIG. **6** in an enlarged manner.

[0200] The tempering conditions and glass characteristics of Examples 3-1 and 3-2 are shown in Table 32.

TABLE 32

Example number		3-1	3-2
Sample No.		No. 106	No. 247
Thickness (mm)		0.7	0.7
First ion exchange	Molten salt for tempering	$NaNO_3$	$NaNO_3$
	Temperature of molten salt (° C.)	380	380
	Tempering time period (min)	120	210

TABLE 32-continued

Example number		3-1	3-2
Second ion exchange	Molten salt for tempering	KNO_3	KNO_3
	Temperature of molten salt (° C.)	410	410
	Tempering time period (min)	24	25
CS (MPa)		892	898
De (μm)		5.5	5.8
DOC (μm)		127	126
CT (MPa)		95	93
CS30 (MPa)		146	156
CS50 (MPa)		111	118
SPP-4PB (MPa)		206	199

[0201] Each of the samples (Examples 3-1 and 3-2) was measured for the stress values and the depth of compression, and was then measured for the abraded four-point bending strength by the same methods as in Example 2.

[0202] As apparent from Table 32 and FIG. **6** and FIG. **7**, each of the tempered glass sheets of Examples 3-1 and 3-2 had a compressive stress value (CS) of the compressive stress layer on the outermost surface and a compressive stress value (CS30) thereof at a depth of 30 μm from the outermost surface as high as 892 MPa or more and 146 MPa or more, respectively. In addition, the abraded four-point bending strength is as high as 199 MPa or more, and hence it is conceived that each of the tempered glass sheets is less liable to be broken at the time of dropping.

EXAMPLE 4

[0203] An untempered glass sheet (glass sheet to be tempered) having the same composition as that of Sample No. 277 of Example 1 and having a thickness of 0.7 mm was immersed in a $NaNO_3$ molten salt at 380° C. for a time period shown in Table 33, and was then immersed in a KNO_3 molten salt at 430° C. for a time period shown in Table 33. Thus, a tempered glass sheet was obtained.

[0204] Further, the resultant tempered glass sheet was measured for its stress profile by the same method as in Example 2. FIG. **8** is a graph showing the general view of stress profiles of Examples 4-1 to 4-4, and FIG. **9** is a graph showing low compressive stress regions in the stress profiles of FIG. **8** in an enlarged manner.

[0205] The tempering conditions and glass characteristics of Examples 4-1 to 4-4 are shown in Table 33.

TABLE 33

Example number		4-1	4-2	4-3	4-4
Sample No.		No. 277			
Thickness (mm)		0.7	0.7	0.7	0.7
First ion exchange	Molten salt for tempering	$NaNO_3$	$NaNO_3$	$NaNO_3$	$NaNO_3$
	Temperature of molten salt (° C.)	380	380	380	380
	Tempering time period (min)	2,780	600	4,320	2,780
Second ion exchange	Molten salt for tempering	KNO_3	KNO_3	KNO_3	KNO_3
	Temperature of molten salt (° C.)	380	380	380	380
	Tempering time period (min)	105	150	105	210

TABLE 33-continued

Example number	4-1	4-2	4-3	4-4
CS (MPa)	739	735	766	713
De (μm)	6.6	7.0	6.6	8.8
DOC (μm)	120	98	124	120
CT (MPa)	62	42	64	64
CS30 (MPa)	113	91	107	99
CS50 (MPa)	83	58	80	74
SPP-4PB (MPa)	167	152	163	158

[0206] Each of the samples (Examples 4-1 to 4-4) was measured for the stress values and the depth of compression, and was then measured for the abraded four-point bending strength by the same methods as in Example 2.

[0207] As apparent from Table 33 and FIG. **8** and FIG. **9**, the tempered glass sheet of Example 4-1 had a compressive stress value (CS) of the compressive stress layer on the outermost surface and a compressive stress value (CS30) thereof at a depth of 30 μm from the outermost surface as high as 739 MPa and 113 MPa, respectively. In addition, the abraded four-point bending strength is as high as 167 MPa, and hence it is conceived that the tempered glass sheet is less liable to be broken at the time of dropping.

EXAMPLE 5

[0208] An Untempered glass sheet (glass sheet to be tempered) having the same composition as that of the sample described in Example 1 (the number of the sample is shown in each of Tables 34 to 41) and having a thickness of 0.7 mm was immersed in a molten salt shown in each of Tables 34 to 41 for a time period shown therein. Thus, a tempered glass sheet having been subjected to two-step ion exchange was obtained.

[0209] The tempering conditions and glass characteristics of Examples 5-1 to 5-86 are shown in Tables 34 to 41.

TABLE 34

		Example number									
Sample No.		5-1 No. 001	5-2 No. 008	5-3 No. 036	5-4 No. 038	5-5 No. 044	5-6 No. 051	5-7 No. 053	5-8 No. 055	5-9 No. 065	5-10 No. 067
Thickness (mm)		0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
First ion exchange	Molten salt for tempering ($KNO_3/NaNO_3$)	0/100	0/100	0/100	0/100	0/100	0/100	0/100	0/100	0/100	0/100
	Temperature of molten salt (° C.)	380	380	380	380	380	380	380	380	380	380
	Tempering time period (min)	240	300	180	180	90	150	210	300	270	270
Second ion exchange	Molten salt for tempering ($KNO_3/NaNO_3$)	100/0	100/0	100/0	100/0	100/0	100/0	100/0	100/0	100/0	100/0
	Temperature of molten salt (° C.)	430	430	430	430	430	430	430	430	430	430
	Tempering time period (min)	30	30	60	75	30	45	75	75	30	30
$CS30_{1st}$ (MPa)		163	163	155	159	153	217	212	231	167	181
$CS30_{2nd}$ (MPa)		116	95	68	74	77	92	80	125	106	107
$CS30_{Drop}$ (MPa)		47	68	86	85	76	124	132	106	61	75
$CS30_{Drop\ rate}$		0.29	0.42	0.56	0.53	0.50	0.57	0.62	0.46	0.36	0.41
DOC_{Na}/DOL_K		4.8	5.1	7.1	8.0	6.1	6.6	8.7	9.0	5.7	5.9

TABLE 35

		Example number									
Sample No.		5-11 No. 068	5-12 No. 069	5-13 No. 071	5-14 No. 072	5-15 No. 073	5-16 No. 074	5-17 No. 075	5-18 No. 076	5-19 No. 077	5-20 No. 078
Thickness (mm)		0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
First ion exchange	Molten salt for tempering ($KNO_3/NaNO_3$)	0/100	0/100	0/100	0/100	0/100	0/100	0/100	0/100	0/100	0/100
	Temperature of molten salt (° C.)	380	380	380	380	380	380	380	380	380	380
	Tempering time period (min)	180	180	210	150	180	300	450	180	210	180
Second ion exchange	Molten salt for tempering ($KNO_3/NaNO_3$)	100/0	100/0	100/0	100/0	100/0	97.5/2.5	100/0	100/0	100/0	100/0
	Temperature of molten salt (° C.)	430	430	430	430	430	380	430	430	430	430
	Tempering time period (min)	45	60	45	45	45	180	45	60	60	45

TABLE 35-continued

Sample No.	Example number									
	5-11 No. 068	5-12 No. 069	5-13 No. 071	5-14 No. 072	5-15 No. 073	5-16 No. 074	5-17 No. 075	5-18 No. 076	5-19 No. 077	5-20 No. 078
$CS30_{1st}$ (MPa)	195	207	187	213	230	177	207	180	192	195
$CS30_{2nd}$ (MPa)	107	92	118	84	109	106	137	81	96	98
$CS30_{Drop}$ (MPa)	89	115	69	129	121	71	70	98	96	97
$CS30_{Drop\ rate}$	0.45	0.56	0.37	0.61	0.53	0.40	0.34	0.55	0.50	0.50
DOC_{Na}/DOL_K	6.9	7.1	6.9	6.8	7.1	6.3	6.5	8.7	7.7	7.5

TABLE 36

	Sample No.	Example number									
		5-21 No. 079	5-22 No. 080	5-23 No. 081	5-24 No. 084	5-25 No. 085	5-26 No. 086	5-27 No. 087	5-28 No. 088	5-29 No. 089	5-30 No. 090
Thickness (mm)		0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
First ion exchange	Molten salt for tempering ($KNO_3/NaNO_3$)	0/100	0/100	0/100	0/100	0/100	0/100	0/100	0/100	0/100	0/100
	Temperature of molten salt (° C.)	380	380	380	380	380	380	380	380	380	380
	Tempering time period (min)	210	120	150	240	300	240	360	240	240	180
Second ion exchange	Molten salt for tempering ($KNO_3/NaNO_3$)	100/0	100/0	100/0	95/5	95/5	95/5	95/5	95/5	95/5	95/5
	Temperature of molten salt (° C.)	430	430	430	410	410	410	410	410	410	410
	Tempering time period (min)	45	30	45	60	90	120	105	60	75	60
$CS30_{1st}$ (MPa)		201	140	188	171	199	214	205	203	227	221
$CS30_{2nd}$ (MPa)		107	78	79	108	108	122	111	137	133	137
$CS30_{Drop}$ (MPa)		94	62	109	63	92	93	94	65	94	85
$CS30_{Drop\ rate}$		0.47	0.44	0.58	0.37	0.46	0.43	0.46	0.32	0.41	0.38
DOC_{Na}/DOL_K		7.0	6.9	7.5	7.1	7.0	8.1	7.6	7.1	6.7	8.0

TABLE 37

	Sample No.	Example number									
		5-31 No. 091	5-32 No. 092	5-33 No. 093	5-34 No. 093	5-35 No. 098	5-36 No. 208	5-37 No. 208	5-38 No. 213	5-39 No. 214	5-40 No. 215
Thickness (mm)		0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
First ion exchange	Molten salt for tempering ($KNO_3/NaNO_3$)	0/100	0/100	0/100	0/100	0/100	0/100	0/100	0/100	0/100	0/100
	Temperature of molten salt (° C.)	380	380	380	380	380	380	380	380	380	380
	Tempering time period (min)	240	240	240	240	180	120	120	240	240	120
Second ion exchange	Molten salt for tempering ($KNO_3/NaNO_3$)	95/5	95/5	95/5	100/0	92.5/7.5	92.5/7.5	92.5/7.5	97.5/2.5	97.5/2.5	97.5/2.5
	Temperature of molten salt (° C.)	410	410	410	380	380	410	410	410	410	410
	Tempering time period (min)	90	75	60	120	55	24	24	30	30	30
$CS30_{1st}$ (MPa)		191	205	190	267	205	196	196	176	218	200
$CS30_{2nd}$ (MPa)		103	124	120	164	158	143	146	138	152	125
$CS30_{Drop}$ (MPa)		88	81	70	102	48	54	51	38	66	75
$CS30_{Drop\ rate}$		0.46	0.40	0.37	0.38	0.23	0.27	0.26	0.22	0.30	0.38
DOC_{Na}/DOL_K		8.8	7.5	7.5	6.0	4.5	4.5	4.2	4.5	4.8	4.0

TABLE 38

Sample No.		Example number 5-41 No. 216	5-42 No. 217	5-43 No. 218	5-44 No. 219	5-45 No. 221	5-46 No. 222	5-47 No. 223	5-48 No. 224	5-49 No. 225	5-50 No. 226
Thickness (mm)		0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
First ion exchange	Molten salt for tempering ($KNO_3/NaNO_3$)	0/100	0/100	0/100	0/100	0/100	0/100	0/100	0/100	0/100	0/100
	Temperature of molten salt (° C.)	380	380	380	380	380	380	380	380	380	380
	Tempering time period (min)	180	120	240	180	180	240	120	180	240	120
Second ion exchange	Molten salt for tempering ($KNO_3/NaNO_3$)	97.5/2.5	97.5/2.5	97.5/2.5	97.5/2.5	97.5/2.5	97.5/2.5	97.5/2.5	92.5/7.5	97.5/2.5	97.5/2.5
	Temperature of molten salt (° C.)	410	410	410	410	410	410	410	410	410	410
	Tempering time period (min)	30	15	45	30	45	30	30	25	30	15
$CS30_{1st}$ (MPa)		192	200	207	148	202	176	196	168	182	159
$CS30_{2nd}$ (MPa)		144	151	141	90	131	133	128	147	99	125
$CS30_{Drop}$ (MPa)		47	50	66	57	71	43	68	21	83	34
$CS30_{Drop\ rate}$		0.25	0.25	0.32	0.39	0.35	0.24	0.35	0.13	0.46	0.21
DOC_{Na}/DOL_K		4.8	4.3	5.4	4.2	4.6	4.2	4.4	2.9	4.0	3.3

TABLE 39

Sample No.		Example number 5-51 No. 227	5-52 No. 228	5-53 No. 229	5-54 No. 230	5-55 No. 231	5-56 No. 232	5-57 No. 233	5-58 No. 235	5-59 No. 236	5-60 No. 237
Thickness (mm)		0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
First ion exchange	Molten salt for tempering ($KNO_3/NaNO_3$)	0/100	0/100	0/100	0/100	0/100	0/100	0/100	0/100	0/100	0/100
	Temperature of molten salt (° C.)	380	380	380	380	380	380	380	380	380	380
	Tempering time period (min)	180	180	240	180	240	360	180	120	180	180
Second ion exchange	Molten salt for tempering ($KNO_3/NaNO_3$)	97.5/2.5	97.5/2.5	97.5/2.5	97.5/2.5	97.5/2.5	97.5/2.5	97.5/2.5	97.5/2.5	97.5/2.5	97.5/2.5
	Temperature of molten salt (° C.)	410	410	410	410	410	410	410	410	410	410
	Tempering time period (min)	30	30	30	45	45	75	25	25	60	25
$CS30_{1st}$ (MPa)		245	264	277	295	268	337	173	197	192	187
$CS30_{2nd}$ (MPa)		175	175	210	211	211	246	126	127	118	130
$CS30_{Drop}$ (MPa)		70	89	67	84	57	91	46	70	74	57
$CS30_{Drop\ rate}$		0.29	0.34	0.24	0.28	0.21	0.27	0.27	0.36	0.39	0.31
DOC_{Na}/DOL_K		4.3	4.5	4.7	4.9	5.1	6.3	4.6	4.5	5.7	4.4

TABLE 40

Sample No.		Example number 5-61 No. 238	5-62 No. 239	5-63 No. 240	5-64 No. 241	5-65 No. 242	5-66 No. 243	5-67 No. 244	5-68 No. 245	5-69 No. 247	5-70 No. 248
Thickness (mm)		0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
First ion exchange	Molten salt for tempering ($KNO_3/NaNO_3$)	0/100	0/100	0/100	0/100	0/100	0/100	0/100	0/100	0/100	0/100
	Temperature of molten salt (° C.)	380	380	380	380	380	380	380	380	380	380
	Tempering time period (min)	180	180	180	180	180	180	240	180	90	180

TABLE 40-continued

		Example number									
Sample No.		5-61 No. 238	5-62 No. 239	5-63 No. 240	5-64 No. 241	5-65 No. 242	5-66 No. 243	5-67 No. 244	5-68 No. 245	5-69 No. 247	5-70 No. 248
Second ion exchange	Molten salt for tempering ($KNO_3/NaNO_3$)	97.5/2.5	97.5/2.5	97.5/2.5	97.5/2.5	97.5/2.5	97.5/2.5	97.5/2.5	97.5/2.5	92.5/7.5	97.5/2.5
	Temperature of molten salt (° C.)	410	410	410	410	410	410	410	410	410	410
	Tempering time period (min)	30	30	45	15	25	25	20	30	25	15
$CS30_{1st}$ (MPa)		176	241	250	189	222	194	184	215	187	185
$CS30_{2nd}$ (MPa)		122	168	157	140	156	154	136	134	151	139
$CS30_{Drop}$ (MPa)		54	73	93	49	66	40	48	81	36	46
$CS30_{Drop\ rate}$		0.31	0.30	0.37	0.26	0.30	0.21	0.26	0.38	0.19	0.25
DOC_{Na}/DOL_K		4.6	4.3	5.0	3.4	4.4	3.9	3.0	4.3	3.7	3.8

TABLE 41

		Example number						
Sample No.		5-71 No. 249	5-72 No. 250	5-73 No. 252	5-74 No. 253	5-75 No. 254	5-76 No. 255	5-77 No. 256
Thickness (mm)		0.7	0.7	0.7	0.7	0.7	0.7	0.7
First ion exchange	Molten salt for tempering ($KNO_3/NaNO_3$)	0/100	0/100	0/100	0/100	0/100	0/100	0/100
	Temperature of molten salt (° C.)	380	380	380	380	380	380	380
	Tempering time period (min)	90	90	90	90	90	90	90
Second ion exchange	Molten salt for tempering ($KNO_3/NaNO_3$)	92.5/7.5	92.5/7.5	92.5/7.5	92.5/7.5	92.5/7.5	92.5/7.5	92.5/7.5
	Temperature of molten salt (° C.)	410	410	410	410	410	410	410
	Tempering time period (min)	30	30	30	30	30	35	35
$CS30_{1st}$ (MPa)		246	215	206	226	210	251	225
$CS30_{2nd}$ (MPa)		199	168	157	173	162	200	191
$CS30_{Drop}$ (MPa)		47	47	49	53	48	51	34
$CS30_{Drop\ rate}$		0.19	0.22	0.24	0.24	0.23	0.20	0.15
DOC_{Na}/DOL_K		3.6	3.7	3.5	3.7	3.6	3.9	3.9

[0210] For each of the resultant samples (Examples 5-1 to 5-86), the tempered glass sheet after first ion exchange was measured for its compressive stress value ($CS30_{1st}$) at a depth of 30 μm, and the tempered glass sheet after second ion exchange was measured for its compressive stress value ($CS30_{2nd}$) at a depth of 30 μm with a scattered light photoelastic stress meter SLP-2000 (manufactured by Orihara Industrial Co., Ltd.), and a compressive stress drop rate ($CS30_{Droprate}$) at a depth of 30 μm was calculated.

[0211] As apparent from Tables 34 to 41, each of the tempered glass sheets of Examples 5-1 to 5-86 had a compressive stress drop rate ($CS30_{Droprate}$) as low as 0.61 or less. It is conceived that a stress profile having an inflection point as illustrated in FIG. **3** is easily made, and each of the tempered glass sheets is less liable to be broken at the time of dropping.

EXAMPLE 6

[0212] Each of Samples No. 055, No. 072, No. 106, No. 116, and No. 247 of Example 1 was measured for a Na ion mutual diffusion coefficient D_{Na} and a K ion mutual diffusion coefficient D_K.

[0213] First, a glass sheet to be tempered having the same composition as that of each of the above-mentioned samples was prepared, and was ion exchanged with 100% $NaNO_3$ at 380° C. for a time period "t" shown in Table 42. Thus, a tempered glass sheet was obtained. After that, a Na ion concentration distribution on a cut surface thereof was measured through EPMA line scan. The EPMA measurement was performed by using JXA-8100 manufactured by JEOL Ltd. and by setting an acceleration voltage to 15 kV, a current to 500 nA, a measurement pitch to 0.82 μm, and an electron beam diameter to 2 μm.

[0214] The resultant ion concentration distribution was approximated to a curve through use of an analytical solution of Fick's laws of diffusion. Specifically, the concentra-

tion distribution at a tempering time period "t" obtained with an EPMA was normalized through use of a Na ion concentration C_{max} on the outermost surface (x=0) and a Na ion concentration C_{min} in a deep region (x=+), and the respective values were then input into the above-mentioned equation of [Math. 1] so as to achieve fitting to the complementary error function erfc(x/√4Dt), and the value of D was derived through use of a least squares method and used as a mutual diffusion coefficient D_{Na}. The Na ion concentration C_{min} in the deep region (x=+∞) was set to an average of Na ion concentrations at depths of from 300 μm to 400 μm. Plots of the measurement values of Na ion concentrations, which had been measured with an EPMA for a tempered glass sheet obtained by subjecting Sample No. 247 to ion exchange under the conditions shown in Table 42, and the result obtained by approximating the measurement values to the complementary error function are shown in FIG. **10**.

[0215] The K ion mutual diffusion coefficient D_K was derived by the same method as the above-mentioned calculation method for the mutual diffusion coefficient D_{Na} except that the molten salt to be used was changed to 100 KNO_3 and the target of the EPMA measurement was changed to a K ion.

TABLE 42

		Example number				
	Sample No.	6-1 No. 055	6-2 No. 072	6-3 No. 116	6-4 No. 106	6-5 No. 247
Measurement of Na ion mutual diffusion coefficient	Thickness (mm)	0.7	0.7	0.7	0.7	0.7
	Molten salt for tempering	100% $NaNO_3$	100% $NaNO_3$	100% $NaNO_3$	100% $NaNO_3$	100% $NaNO_3$
	Temperature of molten salt (° C.)	380	380	380	380	380
	Tempering time period "t" (min)	80	240	390	70	60
	DOC (μm)	75	108	121	120	98
	C_Na, max (mol %)	498	587	624	613	726
	C_Na, min (mol %)	129	172	234	378	423
	D_{Na} ($\times 10^{-13}$ m^2/sec)	1.52	1.96	1.79	8.59	9.83
Measurement of K ion mutual diffusion coefficient	Thickness (mm)	0.7	0.7	0.7	0.7	0.7
	Molten salt for tempering	100% KNO_3	100% KNO_3	100% KNO_3	100% KNO_3	100% KNO_3
	Temperature of molten salt (° C.)	380	380	380	380	380
	Tempering time period (min)	390	180	120	57	57
	DOL (μm)	4.8	5.2	4.5	6.7	6.6
	C_K, max (mol %)	1,763	1,276	1,558	1,594	1,859
	C_K, min (mol %)	15	16	16	73	179
	D_K ($\times 10^{-16}$ m^2/sec)	1.19	3.02	2.95	15.1	14.9
Mutual diffusion coefficient ratio D_K/D_{Na}		0.0008	0.0015	0.0017	0.0018	0.0015

[0216] Further, an untempered glass sheet (glass sheet to be tempered) having the same composition as that of each of Samples No. 055, No. 072, No. 106, No. 116, and No. 247 of Example 1 and having a thickness of 0.7 mm was subjected to first ion exchange under the conditions shown in Table 43, and was then subjected to second ion exchange under the conditions shown in the same table. Thus, a tempered glass sheet was obtained.

TABLE 43

		Example number				
	Sample No.	6-1 No. 055	6-2 No. 072	6-3 No. 116	6-4 No. 106	6-5 No. 247
Thickness (mm)		0.7	0.7	0.7	0.7	0.7
First ion exchange	Molten salt for tempering ($KNO_3/NaNO_3$)	0/100	0/100	0/100	0/100	0/100
	Temperature of molten salt (° C.)	380	380	380	380	380
	Tempering time period (min)	300	300	240	120	105
	CS (MPa)	350	334	402	306	349
	$CS30_{1st}$ (MPa)	231	224	267	196	225
	DOC (μm)	110	119	106	115	112

TABLE 43-continued

		Example number				
	Sample No.	6-1 No. 055	6-2 No. 072	6-3 No. 116	6-4 No. 106	6-5 No. 247
Second ion exchange	Molten salt for tempering ($KNO_3/NaNO_3$)	100/0	97.5/2.5	100/0	92.5/7.5	92.5/7.5
	Temperature of molten salt (° C.)	430	380	380	410	410
	Tempering time period (min)	75	180	120	24	25
	CS (MPa)	1,031	725	950	892	908
	De (μm)	5.0	5.0	5.0	5.5	5.8
	DOC (μm)	142	136	127	127	120
	CT(MPa)	90.0	88	84.0	95.0	88.0
	$CS30_{2nd}$ (MPa)	125	143	164	146	164
$CS30_{Droprate}$		0.46	0.36	0.39	0.26	0.27
SPP-4PB (MPa)		176	189	204	206	199

[0217] Each of the resultant samples (Examples 6-1 to 6-5) was measured for the compressive stress values and the value of the depth of compression, and was then measured for the abraded four-point bending strength by the same methods as in Examples 2 to 5.

[0218] As apparent from Table 42 and Table 43, each of the tempered glass sheets of Examples 6-1 to 6-5 had a mutual diffusion coefficient ratio D_K/D_{Na} of 0.0008 or more and a compressive stress drop rate ($CS30_{Droprate}$) of 0.46 or less, and after the two-step ion exchange, had a compressive stress value (CS) of the compressive stress layer on the outermost surface and a compressive stress value (CS30) thereof at a depth of 30 μm from the outermost surface as high as 725 MPa or more and 125 MPa or more, respectively. In addition, the abraded four-point bending strength is as high as 176 MPa or more, and hence it is conceived that each of the tempered glass sheets is less liable to be broken at the time of dropping.

INDUSTRIAL APPLICABILITY

[0219] The tempered glass sheet of the present invention is suitable as a cover glass for a touch panel display of a cellular phone, a digital camera, a personal digital assistant (PDA), or the like. In addition, the tempered glass sheet of the present invention is expected to find applications for which high mechanical strength is required, for example, a window glass, a substrate for a magnetic disk, a substrate for a flat panel display, a substrate for a flexible display, a cover glass for a solar cell, a cover glass for a solid state image sensor, and a cover glass for an automobile, in addition to the above-mentioned applications.

REFERENCE SIGNS LIST

[0220] a first peak

[0221] b first bottom

[0222] c second peak

[0223] d second bottom

[0224] e inflection point

1. A tempered glass sheet having a compressive stress layer in a surface thereof,

the tempered glass sheet comprising as a glass composition, in terms of mol %, 50% to 80% of SiO_2, 7% to 25% of Al_2O_3, 0% to 15% of B_2O_3, 0% to 15% of Li_2O, 0% to 25% of Na_2O, 0% to 10% of K_2O, 0% to 15% of MgO, 0% to 10% of CaO, 0% to 10% of SrO, 0% to 10% of BaO, 0% to 10% of ZnO, 0% to 15% of P_2O_5, 0% to 10% of TiO_2, 0% to 10% of ZrO_2, and 0% to 0.30% of SnO_2, having a value of $[B_2O_3]+[MgO]+[CaO]$ of from 0.1% to 30%, and having a value of $([Li_2O]+[Na_2O]+[K_2O])/[Al_2O_3]$ of from 0.5 to 2.0.

2. The tempered glass sheet according to claim **1**, wherein the tempered glass sheet has a Z value calculated by the following equation of 18.0 or more.

$$Z = 0.13\times[SiO_2] + 2.36\times[Al_2O_3] - 0.14\times[B_2O_3] + 4.90\times[Li_2O] - 5.53\times[Na_2O] - 2.14\times[MgO] - 2.34\times[CaO]$$

3. The tempered glass sheet according to claim **2**, wherein the tempered glass sheet has a Z value calculated by the following equation of 20.0 or more.

$$Z = 0.13\times[SiO_2] + 2.36\times[Al_2O_3] - 0.14\times[B_2O_3] + 4.90\times[Li_2O] - 5.53\times[Na_2O] - 2.14\times[MgO] - 2.34\times[CaO]$$

4. The tempered glass sheet according to claim **1**, wherein the tempered glass sheet has a molar ratio $[Na_2O]/[Li_2O]$ of 1.0 or less.

5. The tempered glass sheet according to claim **1**, wherein the tempered glass sheet has a Y value calculated by the following equation of 5.0 or more.

$$Y = 3 + 0.21\times[SiO_2] + 0.25\times[Al_2O_3] - 0.33\times[B_2O_3] - 0.55\times[Li_2O] + 0.45\times[Na_2O] - 0.97\times[MgO] - 1.46\times[CaO]$$

6. The tempered glass sheet according to claim **5**, wherein the tempered glass sheet has a Y value calculated by the following equation of from 6.0 to 30.

$$Y = 3 + 0.21\times[SiO_2] + 0.25\times[Al_2O_3] - 0.33\times[B_2O_3] - 0.55\times[Li_2O] + 0.45\times[Na_2O] - 0.97\times[MgO] - 1.46\times[CaO]$$

7. The tempered glass sheet according to claim 1, wherein the tempered glass sheet has an X value calculated by the following equation of 300 or more.

$$X = -1.49 \times [SiO_2] + 26.98 \times [Al_2O_3] - 3.23 \times [B_2O_3] + 48.56 \times [Li_2O] - 24.31 \times [Na_2O] - 0.28 \times [MgO] + 2.74 \times [CaO]$$

8. The tempered glass sheet according to claim 1, wherein the tempered glass sheet has a W value calculated by the following equation of 340 or more.

$$W = 0.07 \times [SiO_2] + 18.17 \times [Al_2O_3] - 4.42 \times [B_2O_3] + 41.43 \times [Li_2O] - 29.30 \times [Na_2O] + 1.43 \times [MgO] - 10.43 \times [CaO]$$

9. The tempered glass sheet according to claim 1, wherein the tempered glass sheet has a value of $[Al_2O_3]+[Li_2O]+[Na_2O]+[K_2O]$ of 10.5% or more.

10. The tempered glass sheet according to claim 1, wherein the tempered glass sheet has a molar ratio $[Li_2O]/[Al_2O_3]$ of 0.1 or more.

11. The tempered glass sheet according to claim 1, wherein the tempered glass sheet has a U value calculated by the following equation of 7,000 or more.

$$U = 87.39 \times [SiO_2] + 180.12 \times [Al_2O_3] + 93.63 \times [B_2O_3] + 113.78 \times ([MgO] + [CaO] + [BaO] + [SrO]) - 46.2 \times [Li_2O] - 71.1 \times [Na_2O] - 58.6 \times [K_2O] - 40.0 \times [P_2O_5]$$

12. The tempered glass sheet according to claim 1, wherein the tempered glass sheet has a Q value calculated by the following equation of −30 or more.

$$Q = [SiO_2] + 1.2 \times [P_2O_5] - 3 \times [Al_2O_3] - [B_2O_3] - 2 \times [Li_2O] - 1.5 \times [Na_2O] - [K_2O]$$

13. The tempered glass sheet according to claim 1, wherein the tempered glass sheet comprises Cl as the glass composition and has a content of Cl of 0.02 mol % or more.

14. The tempered glass sheet according to claim 1, wherein the tempered glass sheet comprises MoO_3 as the glass composition and has a content of MoO_3 of 0.0001 mol % or more.

15. The tempered glass sheet according to claim 1, wherein the tempered glass sheet has a softening point (Ts) of 920° C. or less.

16. The tempered glass sheet according to claim 1,

wherein a compressive stress value CS of the compressive stress layer on an outermost surface is from 200 MPa to 1,400 MPa, and

wherein a depth of compression DOC of the compressive stress layer is from 3 μm to 200 μm.

17. The tempered glass sheet according to claim 1,

wherein a depth of compression DOC of the compressive stress layer is from 50 μm to 200 μm, and

wherein a compressive stress value CS30 of the compressive stress layer at a depth of 30 μm from an outermost surface is from 35 MPa to 400 MPa.

18. The tempered glass sheet according to claim 1, wherein the tempered glass sheet has a temperature at a viscosity at high temperature of $10^{2.5}$ dPa·s of 1,680° C. or less.

19. The tempered glass sheet according to claim 1, wherein the tempered glass sheet has an overflow-merged surface in an inside thereof.

20. The tempered glass sheet according to claim 1, wherein a stress profile of the tempered glass sheet in a thickness direction has an inflection point.

21. A tempered glass sheet, comprising as a glass composition, in terms of mol %, 50% to 80% of SiO_2, 7% to 25% of Al_2O_3, 1% to 15% of B_2O_3, 0% to 15% of Li_2O, 0% to 25% of Na_2O, 0% to 10% of K_2O, 0% to 15% of MgO, 0% to 10% of CaO, 0% to 10% of BaO, 0% to 10% of SrO, 0% to 10% of ZnO, 0% to 4% of P_2O_5, 0.001% to 0.1% of TiO_2, 0% to 10% of ZrO_2, 0.001% to 0.1% of Fe_2O_3, and 0.001% to 0.30% of SnO_2, having a value of $[B_2O_3]+[MgO]+[CaO]$ of from 0.1% to 30%, and having a value of $([Li_2O]+[Na_2O]+[K_2O])/[Al_2O_3]$ of from 0.5 to 2.0.

22. A method of manufacturing a tempered glass sheet, comprising:

a preparation step of preparing a glass sheet to be tempered including as a glass composition, in terms of mol %, 50% to 80% of SiO_2, 7% to 25% of Al_2O_3, 0% to 15% of B_2O_3, 0% to 15% of Li_2O, 0% to 25% of Na_2O, 0% to 10% of K_2O, 0% to 15% of MgO, 0% to 10% of CaO, 0% to 10% of BaO, 0% to 10% of SrO, 0% to 10% of ZnO, 0% to 15% of P_2O_5, 0% to 10% of TiO_2, 0% to 10% of ZrO_2, and 0% to 0.30% of SnO_2, having a value of $[B_2O_3]+[MgO]+[CaO]$ of from 0.1% to 30%, and having a value of $([Li_2O]+[Na_2O]+[K_2O])/[Al_2O_3]$ of from 0.5 to 2.0; and

an ion exchange step of subjecting the glass sheet to be tempered to ion exchange treatment a plurality of times to provide a tempered glass sheet having a compressive stress layer in a surface thereof.

23. A glass sheet to be tempered, comprising as a glass composition, in terms of mol %, 50% to 80% of SiO_2, 7% to 25% of Al_2O_3, 0% to 15% of B_2O_3, 0% to 15% of Li_2O, 0% to 25% of Na_2O, 0% to 10% of K_2O, 0% to 15% of MgO, 0% to 10% of CaO, 0% to 10% of BaO, 0% to 10% of SrO, 0% to 10% of ZnO, 0% to 15% of P_2O_5, 0% to 10% of TiO_2, 0% to 10% of ZrO_2, and 0% to 0.30% of SnO_2, having a value of $[B_2O_3]+[MgO]+[CaO]$ of from 0.1% to 30%, and having a value of $([Li_2O]+[Na_2O]+[K_2O])/[Al_2O_3]$ of from 0.5 to 2.0.

24. The glass sheet to be tempered according to claim 23,

wherein the glass sheet to be tempered has a Na ion mutual diffusion coefficient D_{Na} at 380° C. of from 1×10^{-14} m^2 sec^{-1} to 1×10^{-11} m^2 sec^{-1},

wherein the glass sheet to be tempered has a K ion mutual diffusion coefficient D_K at 380° C. of from 1×10^{-17} m^2 sec^{-1} to 1×10^{-14} m^2 sec^{-1}, and

wherein the glass sheet to be tempered has a ratio D_K/D_{Na} of 0.0001 or more.

* * * * *