the loss of active drug product leading to increased costs. Further, non-catastrophic breakage (i.e., when the glass cracks but does not break) may cause the contents to lose their sterility which, in turn, may result in costly product recalls.

**[0005]** One approach to improving the mechanical durability of the glass package is to thermally temper the glass package. Thermal tempering strengthens glass by inducing a surface compressive stress during rapid cooling after forming. This technique works well for glass articles with flat geometries (such as windows), glass articles with thicknesses > 2 mm, and glass compositions with high thermal expansion. However, pharmaceutical glass packages typically have complex geometries (vial, tubular, ampoule, etc.), thin walls (~1-1.5 mm), and are produced from low expansion glasses (30-55x$10^{-7}K^{-1}$) making glass pharmaceutical packages unsuitable for strengthening by thermal tempering.

**[0006]** Chemical tempering also strengthens glass by the introduction of surface compressive stress. The stress is introduced by submerging the article in a molten salt bath. As ions from the glass are replaced by larger ions from the molten salt, a compressive stress is induced in the surface of the glass. The advantage of chemical tempering is that it can be used on complex geometries, thin samples, and is relatively insensitive to the thermal expansion characteristics of the glass substrate. However, glass compositions which exhibit a moderate susceptibility to chemical tempering generally exhibit poor chemical durability and vice-versa.

**[0007]** Accordingly, a need exists for glass compositions which are chemically durable and susceptible to chemical strengthening by ion exchange for use in glass pharmaceutical packages, and similar applications.

## SUMMARY

**[0008]** In one aspect, the present disclosure provides a glass for pharmaceutical packaging having a glass composition comprising: from about 70 mol.% to about 80 mol.% $SiO_2$; from about 4 mol.% to about 8 mol.% alkaline earth oxide, the alkaline earth oxide comprising MgO and CaO; X mol.% $Al_2O_3$, wherein X is from 4 to about 8; and Y mol.% alkali oxide comprising non-zero amounts of $Na_2O$ and $K_2O$, wherein a concentration of $K_2O$ is from 0.01 to less than 2, Y is about 9-15 mol.% and a ratio of Y:X is greater than 1.

**[0008a]** In another aspect, the present disclosure provides a glass for for pharmaceutical packaging having a glass composition comprising: from about 74 mol.% to about 80 mol.% $SiO_2$; alkaline earth oxide comprising MgO and CaO and a ratio (CaO (mol.%)/(CaO (mol.%)+MgO (mol.%))) is greater than 0 and less than or equal to 0.5 and the CaO is from 0.1 to about 1.0 mol. %; X mol.% $Al_2O_3$, wherein X is from about 4 to about 8; and Y mol.% alkali oxide comprising non-zero amounts of $Na_2O$ and $K_2O$, wherein Y is greater than about 8 mol.%, a ratio of Y:X is greater than or equal to 1, and a ratio of a concentration of $B_2O_3$ (mol.%) to (Y mol.%-X mol.%) is less than or equal to 0.3.

**[0008b]** In yet another aspect, the present disclosure provides a glass for pharmaceutical packaging having a glass composition comprising: from about 70 mol.% to about 80 mol.% $SiO_2$: from about 4 mol.% to about 8 mol.% alkaline earth oxide comprising MgO and CaO and a ratio (CaO (mol.%)/(CaO (mol.%)+MgO (mol.%))) is greater than 0 and less than or equal to 0.5; X mol.% $Al_2O_3$; and Y mol.% alkali oxide comprising non-zero amounts of $Na_2O$ and $K_2O$, wherein Y is about 9-14 mol.%, a ratio of Y:X is greater than or equal to 1 and less than or equal to 2, and a ratio of a concentration of $B_2O_3$ (mol.%) to (Y mol.%-X mol.%) is less than or equal to 0.3.

**[0008c]** In a further aspect, the present disclosure provides a glass for pharmaceutical packaging having a glass composition comprising: from about 70 mol.% to about 80 mol.% $SiO_2$; alkaline earth oxide comprising MgO and CaO and a ratio (CaO (mol.%)/(CaO (mol.%)+MgO (mol.%))) is greater than 0 and less than or equal to 0.5; X mol.% $Al_2O_3$, wherein X is from about 6 to about 8; and Y mol.% alkali oxide comprising non-zero amounts of $Na_2O$ and $K_2O$, wherein Y is from about 9 mol.% to about 15 mol.%.

**[0008d]** According to one example, a glass composition may include: $SiO_2$ in a concentration greater than about 70 mol.% and Y mol.% alkali oxide. The alkali oxide may include $Na_2O$ in an amount greater than about 8 mol.%. The glass composition may be free of boron and compounds of boron.

**[0009]** According to another example, a glass composition may include: greater than about 68 mol.% $SiO_2$; X mol.% $Al_2O_3$; Y mol.% alkali oxide; and $B_2O_3$. The alkali oxide may include $Na_2O$ in an amount greater than about 8 mol%. A ratio ($B_2O_3$ (mol.%)/(Y mol.% – X mol.%) may be greater than 0 and less than 0.3.

**[0010]** In yet another example, a glass article may have a type HGB1 hydrolytic resistance according to ISO 719. The glass article may include greater than about 8 mol.% $Na_2O$ and less than about 4 mol.% $B_2O_3$.

**[0011]** In still another example, a glass pharmaceutical package may include: $SiO_2$ in an amount greater than about 70 mol.%; X mol.% $Al_2O_3$; and Y mol.% alkali oxide. The alkali oxide may include $Na_2O$ in an amount greater than about 8 mol.%. A ratio of a concentration of $B_2O_3$ (mol.%) in the glass pharmaceutical package to (Y mol.% – X mol.%) may be less than 0.3. The glass pharmaceutical package may also have a type HGB1 hydrolytic resistance according to ISO 719.

**[0012]** In another example, a glass composition may include from about 70 mol.% to about 80 mol.% $SiO_2$; from about 3 mol.% to about 13 mol.% alkaline earth oxide; X mol.% $Al_2O_3$; and Y mol.% alkali oxide. The alkali oxide may include $Na_2O$ in an amount greater than about 8 mol.%. A ratio of Y:X may be greater than 1 and the glass composition may be free of boron and compounds of boron.

**[0013]** In yet another example, a glass composition may include: from about 72 mol.% to about 78 mol.% $SiO_2$; from about 4 mol.% to about 8 mol.% alkaline earth oxide; X mol.% $Al_2O_3$; and Y mol.% alkali oxide. The amount of alkaline earth oxide may be greater than or equal to about 4 mol.% and less than or equal to about 8 mol.%. The alkali oxide may include $Na_2O$ in an amount greater than or equal to about 9 mol.% and less than or equal to about 15 mol.%. A ratio of Y:X may be greater than 1. The glass composition may be free of boron and compounds of boron.

**[0014]** In still another example, a glass composition may include: from about 68 mol.% to about 80 mol.% $SiO_2$; from about 3 mol.% to about 13 mol.% alkaline earth oxide; X mol.% $Al_2O_3$; and Y mol.% alkali oxide. The alkali oxide may include $Na_2O$ in an amount greater than about 8 mol.%. The glass composition may also include $B_2O_3$. A ratio ($B_2O_3$ (mol.%)/(Y mol.% – X mol.%) may be greater than 0 and less than 0.3, and a ratio of Y:X may be greater than 1.

**[0015]** In another example, a glass composition may include from about 70 mol.% to about 80 mol.% $SiO_2$; from about 3 mol.% to about 13 mol.% alkaline earth oxide; X mol.% $Al_2O_3$; and Y mol.% alkali oxide. The alkaline earth oxide may include CaO in an amount greater than or equal to about 0.1 mol.% and less than or equal to about 1.0 mol.%. X may be greater

than or equal to about 2 mol.% and less than or equal to about 10 mol.%. The alkali oxide may include from about 0.01 mol.% to about 1.0 mol.% $K_2O$. A ratio of Y:X may be greater than 1. The glass composition may be free of boron and compounds of boron.

**[0016]** In yet another example, a glass composition may include $SiO_2$ in an amount greater than about 70 mol.% and less than or equal to about 80 mol.%; from about 3 mol.% to about 13 mol.% alkaline earth oxide; X mol.% $Al_2O_3$; and Y mol.% alkali oxide. The alkali oxide may include $Na_2O$ in an amount greater than about 8 mol.%. A ratio of a concentration of $B_2O_3$ (mol.%) in the glass composition to (Y mol.% – X mol.%) may be less than 0.3. A ratio of Y:X may be greater than 1.

**[0017]** In another example, a glass article may have a type HGB1 hydrolytic resistance according to ISO 719. The glass article may also have a threshold diffusivity of greater than 16 $\mu m^2/hr$ at a temperature less than or equal to 450°C.

**[0018]** In yet another example, a glass article may have a type HGB1 hydrolytic resistance according to ISO 719. The glass article may also have a compressive stress layer with a depth of layer of greater than 25 μm and a surface compressive stress of greater than or equal to 350 MPa. The glass article may be ion exchange strengthened and the ion exchange strengthening may include treating the glass article in a molten salt bath for a time less than or equal to 5 hours at a temperature less than or equal to 450°C.

**[0019]** Additional features and advantages will be set forth in the detailed description which follows, and in part will be readily apparent to those skilled in the art from that description or recognized by practicing the examples described herein, including the detailed description which follows, the claims, as well as the appended drawings.

**[0020]** It is to be understood that both the foregoing general description and the following detailed description describe various examples and are intended to provide an overview or framework for understanding the nature and character of the claimed subject matter. The accompanying drawings are included to provide a further understanding of the various examples, and are incorporated into and constitute a part of this specification. The drawings illustrate the various examples described herein, and together with the description serve to explain the principles and operations of the claimed subject matter.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0021]** FIG. 1 graphically depicts the relationship between the ratio of alkali oxides to alumina (x-axis) and the strain point, annealing point, and softening point (y-axes) of inventive and comparative glass compositions;

**[0022]** FIG. 2 graphically depicts the relationship between the ratio of alkali oxides to alumina (x-axis) and the maximum compressive stress and stress change (y-axes) of inventive and comparative glass compositions;

**[0023]** FIG. 3 graphically depicts the relationship between the ratio of alkali oxides to alumina (x-axis) and hydrolytic resistance as determined from the ISO 720 standard (y-axis) of inventive and comparative glass compositions;

**[0024]** FIG. 4 graphically depicts diffusivity D (y-axis) as a function of the ratio (CaO/(CaO+MgO)) (x-axis) for inventive and comparative glass compositions;

**[0025]** FIG. 5 graphically depicts the maximum compressive stress (y-axis) as a function of the ratio (CaO/(CaO+MgO)) (x-axis) for inventive and comparative glass compositions;

**[0026]** FIG. 6 graphically depicts diffusivity D (y-axis) as a function of the ratio ($B_2O_3$/($R_2O$-$Al_2O_3$)) (x-axis) for inventive and comparative glass compositions; and

**[0027]** FIG. 7 graphically depicts the hydrolytic resistance as determined from the ISO 720 standard (y-axis) as a function of the ratio ($B_2O_3$/($R_2O$-$Al_2O_3$)) (x-axis) for inventive and comparative glass compositions.

## DETAILED DESCRIPTION

**[0028]** Reference will now be made in detail to various embodiments of glass compositions which exhibit improved chemical and mechanical durability. Such glass compositions are suitable for use in various applications including, without limitation, as pharmaceutical packaging materials. The glass compositions may also be chemically strengthened thereby imparting increased mechanical durability to the glass. The glass compositions described herein may generally comprise silica ($SiO_2$), alumina ($Al_2O_3$), alkaline earth oxides (such as