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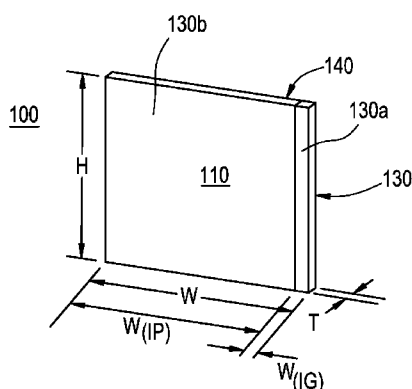
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[Continued on next page]

(54) **Title:** COMPOSITE LIGHT GUIDE PLATE

FIG. 1A



(57) **Abstract:** Compounds, compositions, articles, devices, and methods for the manufacture of light guide plates and back light units including such light guide plates made from a composite structure of glass and plastic. In some embodiments, composite light guide plates (LGP) are provided that have similar or superior optical properties to light guide plates made from PMMA and that have exceptional mechanical properties such as rigidity, CTE and dimensional stability in high moisture conditions as compared to PMMA light guide plates.

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COMPOSITE LIGHT GUIDE PLATE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of priority under 35 U.S.C. § 119 of U.S. Provisional Application Serial No. 62/293572 filed on February 10, 2016, the content of which is relied upon and incorporated herein by reference in its entirety.

BACKGROUND

[0002] Side lit back light units include a light guide plate (LGP) that is usually made of high transmission plastic materials such as polymethylmethacrylate (PMMA). Although such plastic materials present excellent properties such as light transmission, these materials exhibit relatively poor mechanical properties such as rigidity, coefficient of thermal expansion (CTE) and moisture absorption.

[0003] Accordingly, it would be desirable to provide an improved light guide plate having attributes that achieve an improved optical performance in terms of light transmission, scattering and light coupling as well as exhibiting exceptional mechanical performance in terms of rigidity, CTE, and moisture absorption.

SUMMARY

[0004] Aspects of the subject matter pertain to compounds, compositions, articles, devices, and methods for the manufacture of composite light guide plates and back light units including such composite light guide plates made from a composite structure including both glass and plastic. In some embodiments, composite light guide plates (LGPs) are provided that have similar or superior optical properties to light guide plates made from PMMA and that have exceptional mechanical properties such as rigidity, CTE and dimensional stability in high moisture conditions as compared to PMMA light guide plates.

[0005] Principles and embodiments of the present subject matter relate in some embodiments to a composite light guide plate for use in a backlight unit. In some embodiments the composite light guide plate can comprise a composite sheet with a front face having a width and a height, a back face opposite the front face, and a thickness between the front face and back face, forming a first edge, second edge, third edge and fourth edge around the front and back faces, wherein the composite sheet comprises both glass and plastic

materials in a coplanar relationship. In other embodiments, the composite light guide plate can comprise a glass sheet with a front face having a width and a height, a back face opposite the front face, and a thickness between the front face and back face, forming a first edge, second edge, third edge and fourth edge around the front and back faces; and a plastic sheet with a front face having a width and a height, a back face opposite the front face, and a thickness between the front face and back face, forming a first edge, second edge, third edge and fourth edge around the front and back faces, wherein the front faces of the glass and plastic sheets are coplanar with each other, and wherein the back faces of the glass and plastic sheets are coplanar with each other.

[0006] In some embodiments, the plastic material is selected from the group consisting of polymethylmethacrylate (PMMA), polycarbonate (PC), polyethylene terephthalate (PET), polymethylmethacrylate, polyether ether ketone, polyethylene naphthalate, poly(ethylene succinate), polypropylene, styrene-methacrylate copolymer (MS), and cyclic olefin copolymer (COC). In some embodiments, the glass material comprises between about 65.79 mol % to about 78.17 mol% SiO_2 , between about 2.94 mol% to about 12.12 mol% Al_2O_3 , between about 0 mol% to about 11.16 mol% B_2O_3 , between about 0 mol% to about 2.06 mol% Li_2O , between about 3.52 mol% to about 13.25 mol% Na_2O , between about 0 mol% to about 4.83 mol% K_2O , between about 0 mol% to about 3.01 mol% ZnO , between about 0 mol% to about 8.72 mol% MgO , between about 0 mol% to about 4.24 mol% CaO , between about 0 mol% to about 6.17 mol% SrO , between about 0 mol% to about 4.3 mol% BaO , and between about 0.07 mol% to about 0.11 mol% SnO_2 . In some embodiments, the glass material comprises between about 66 mol % to about 78 mol% SiO_2 , between about 4 mol% to about 11 mol% Al_2O_3 , between about 4 mol% to about 11 mol% B_2O_3 , between about 0 mol% to about 2 mol% Li_2O , between about 4 mol% to about 12 mol% Na_2O , between about 0 mol% to about 2 mol% K_2O , between about 0 mol% to about 2 mol% ZnO , between about 0 mol% to about 5 mol% MgO , between about 0 mol% to about 2 mol% CaO , between about 0 mol% to about 5 mol% SrO , between about 0 mol% to about 2 mol% BaO , and between about 0 mol% to about 2 mol% SnO_2 . In some embodiments, the glass material comprises between about 72 mol % to about 80 mol% SiO_2 , between about 3 mol% to about 7 mol% Al_2O_3 , between about 0 mol% to about 2 mol% B_2O_3 , between about 0 mol% to about 2 mol% Li_2O , between about 6 mol% to about 15 mol% Na_2O , between about 0 mol% to about 2 mol% K_2O , between about 0 mol% to about 2 mol% ZnO , between about 2 mol% to about 10 mol% MgO , between about 0 mol% to about 2 mol% CaO , between about 0 mol% to about 2 mol% SrO , between about 0 mol% to about 2 mol% BaO ,

and between about 0 mol% to about 2 mol% SnO_2 . In some embodiments, the glass material comprises between about 60 mol % to about 80 mol% SiO_2 , between about 0 mol% to about 15 mol% Al_2O_3 , between about 0 mol% to about 15 mol% B_2O_3 , and about 2 mol% to about 50 mol% R_xO , wherein R is any one or more of Li, Na, K, Rb, Cs and x is 2, or Zn, Mg, Ca, Sr or Ba and x is 1, and wherein $\text{Fe} + 30\text{Cr} + 35\text{Ni} < \text{about } 60 \text{ ppm}$. Additional suitable compositions are described further herein.

[0007] In some embodiments, the glass material has a CTE between about $49.6 \times 10^{-7}/^\circ\text{C}$ to about $70 \times 10^{-7}/^\circ\text{C}$, between about $30 \times 10^{-7}/^\circ\text{C}$ to about $120 \times 10^{-7}/^\circ\text{C}$, between about $30 \times 10^{-7}/^\circ\text{C}$ to about $55 \times 10^{-7}/^\circ\text{C}$, between about $55 \times 10^{-7}/^\circ\text{C}$ to about $85 \times 10^{-7}/^\circ\text{C}$, and between about $85 \times 10^{-7}/^\circ\text{C}$ to about $120 \times 10^{-7}/^\circ\text{C}$. In some embodiments, the glass material has a density between about 2.34 gm/cc @ 20 C and about 2.53 gm/cc @ 20 C. In some embodiments, the article is a light guide plate. In some embodiments, a display device comprises such a light guide plate. In some embodiments, the thickness of the plate is between about 0.2 mm and about 8 mm. In some embodiments, the thickness has a variation of less than 5%. In some embodiments, the glass material of the light guide plate is manufactured from a fusion draw process, slot draw process, or a float process. In some embodiments, the glass comprises less than 1 ppm each of Co, Ni, and Cr. In some embodiments, the concentration of Fe in the glass material is $< \text{about } 50 \text{ ppm}$, $< \text{about } 20 \text{ ppm}$, or $< \text{about } 10 \text{ ppm}$. In some embodiments, $\text{Fe} + 30\text{Cr} + 35\text{Ni} < \text{about } 60 \text{ ppm}$ in the glass material, $< \text{about } 40 \text{ ppm}$ in the glass material, $< \text{about } 20 \text{ ppm}$ in the glass material, or $< \text{about } 10 \text{ ppm}$ in the glass material. In some embodiments, the transmittance of the glass material at 450 nm with at least 500 mm in length is greater than or equal to 85%, the transmittance of the glass material at 550 nm with at least 500 mm in length is greater than or equal to 90%, or the transmittance of the glass material at 630 nm with at least 500 mm in length is greater than or equal to 85%, and combinations thereof. In some embodiments, the transmittance of the glass material is substantially similar to the transmittance of the plastic material. In some embodiments, the glass material has a color shift < 0.015 or < 0.008 . In some embodiments, the glass material has a color shift substantially similar to the color shift of the plastic material. In some embodiments, the glass material is positioned along the first edge, the second edge, the third edge, the fourth edge, or combinations thereof. In some embodiments, the glass material is positioned at a distance from $0.5 \times \text{width}$ of the article to the first edge (the symbol “*” represents “multiplied by”), $0.4 \times \text{width}$ of the article to the first edge, $0.3 \times \text{width}$ of the article to the first edge, $0.2 \times \text{width}$ of the article to the first edge, $0.1 \times \text{width}$ of the article to the first edge, $0.05 \times \text{width}$ of the article to the first edge, or

0.01*width of the article to the first edge. In some embodiments, the glass material is positioned at a distance from 0.5*height of the article to the second edge, 0.4* height of the article to the second edge, 0.3* height of the article to the second edge, 0.2* height of the article to the second edge, 0.1* height of the article to the second edge, 0.05* height of the article to the second edge, or 0.01* height of the article to the second edge.

[0008] Additional features and advantages of the disclosure 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 methods as described herein, including the detailed description which follows, the claims, as well as the appended drawings.

[0009] It is to be understood that both the foregoing general description and the following detailed description present various embodiments of the disclosure, and are intended to provide an overview or framework for understanding the nature and character of the claims. The accompanying drawings are included to provide a further understanding of the disclosure, and are incorporated into and constitute a part of this specification. The drawings illustrate various embodiments of the disclosure and together with the description serve to explain the principles and operations of the disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[00010] The following detailed description can be further understood when read in conjunction with the following drawings.

[00011] FIGURES 1A-1E are a pictorial illustrations of exemplary embodiments of a composite light guide plate;

[00012] FIGURE 2 is a graph showing percentage light coupling versus distance between an LED and LGP edge;

[00013] FIGURE 3 is a graph showing an expected coupling (without Fresnel losses) as a function of distance between the LGP and LED for a 2mm thick LED's coupled into a 2mm thick LGP;

[00014] FIGURE 4 is a pictorial illustration of a coupling mechanism from an LED to a glass LGP;

[00015] FIGURE 5 is a graph showing an expected angular energy distribution calculated from surface topology; and

[00016] FIGURE 6 is a cross sectional illustration of an exemplary LCD panel with a LGP in accordance with one or more embodiments.

DETAILED DESCRIPTION

[00017] Described herein are composite light guide plates, methods of making composite light guide plates and backlight units utilizing composite light guide plates in accordance with embodiments of the present subject matter.

[00018] Current light guide plates used in LCD backlight applications are typically made from PMMA material since this is one of the best materials in term of optical transmission in the visible spectrum. However, PMMA and other polymers present mechanical problems that make large size (e.g., 50 inch diagonal and greater) displays challenging in term of mechanical design, such as, rigidity, moisture absorption, coefficient of thermal expansion (CTE), and distortion and creep at relatively low temperatures (e.g., less than 150°C, less than 100°C, less than 80°C).

[00019] With regard to rigidity, conventional LCD panels are made of two pieces of thin glass (color filter substrate and TFT substrate) with a PMMA light guide and a plurality of thin plastic films (diffusers, dual brightness enhancement films (DBEF) films, etc.). Due to the poor elastic modulus of PMMA, the overall structure of the LCD panel does not have sufficient rigidity, and additional mechanical structure is necessary to provide stiffness for the LCD panel. It should be noted that PMMA generally has a Young's modulus of about 2 GPa, while certain exemplary glasses have a Young's modulus ranging from about 60 GPa to 90 GPa or more.

[00020] Regarding moisture absorption, humidity testing shows that PMMA is sensitive to moisture and size can change by about 0.5%. For a PMMA panel having a length of one meter, this 0.5% change can increase the length by 5mm, which is significant and makes the mechanical design of a corresponding backlight unit challenging. Conventional means to solve this problem is leaving an air gap between the light emitting diodes (LEDs) and the PMMA light guide plate (LGP) to let the material expand. A problem with this approach is that light coupling is extremely sensitive to the distance from the LEDs to the LGP, which can cause the display brightness to change as a function of humidity. FIG. 2 is a graph showing percentage light coupling versus distance between an LED and LGP edge. With reference to FIG. 2, a relationship is shown which illustrates the drawbacks of conventional measures to solve challenges with PMMA. More specifically, Figure 2 illustrates a plot of light coupling versus LED to LGP distance assuming both are 2mm in

height. It can be observed that the further the distance between LED and LGP, a less efficient light coupling is made between the LED and LGP.

[00021] With regard to CTE, the CTE of PMMA is about $75 \times 10^{-6} \text{ } ^\circ\text{C}^{-1}$ and has relatively low thermal conductivity (0.2 W/m/K) while some glasses have a CTE of about $8 \times 10^{-6} \text{ } ^\circ\text{C}^{-1}$ and a thermal conductivity of 0.8 W/m/K . Of course, the CTE of other glasses can vary and such a disclosure should not limit the scope of the claims appended herewith. PMMA also has a transition temperature of about 105°C , and when used as an LGP, a PMMA LGP material can become very hot whereby its low conductivity makes it difficult to dissipate heat. Thus distortion and/or creep of the PMMA can make PMMA unsuitable for the portion of the LGP closest to the heat source. Other polymers such as styrene-methacrylate copolymer (MS), polycarbonate (PC), or cyclic olefin copolymer (COC) have glass transition temperatures below 200°C and even below 150°C and can also significantly distort and/or creep if exposed to high temperatures (e.g., high intensity LEDs). Accordingly, using a composite glass and plastic structure instead of PMMA as a material for light guide plates provides benefits in this regard, but conventional glass has a relatively poor transmission compared to PMMA due mostly to iron and other impurities.

[00022] Composite Light Guide Plate Structure and Composition

[00023] FIGS. 1A-1E are a pictorial illustrations of exemplary embodiments of a composite light guide plate. With reference to FIGS. 1A-1E, an illustration is provided of an exemplary embodiment having a shape and structure of an exemplary composite light guide plate 100 comprising a composite sheet of material (e.g., plastic and glass) having a first face 110 (i.e., a first major face), which may be a front face, and a second face (i.e., a second major face) opposite the first face, which may be a back face. The first and second faces may have a height, H, and a width, W. The first and/or second face(s) may have a roughness that is less than 0.6 nm, less than 0.5 nm, less than 0.4 nm, less than 0.3 nm, less than 0.2 nm, less than 0.1 nm, or between about 0.1 nm and about 0.6 nm.

[00024] The sheet may have a thickness, T, between the front face and the back face, where the thickness forms four edges. The thickness of the sheet may be less than the height and width of the front and back faces. In various embodiments, the thickness of the plate may be less than 1.5% of the height of the front and/or back face. Alternatively, the thickness, T, may be less than about 3 mm, less than about 2 mm, less than about 1 mm, or between about 0.1 mm to about 3 mm. The height, width, and thickness of the composite light guide plate may be configured and dimensioned for use in an LCD backlight application.

[00025] With reference to FIG. 1A, a first edge 130 may be a light injection edge that receives light provided for example by a light emitting diode (LED). All or a portion of the first edge 130 may be comprised of a glass or glass-ceramic material 130a. The glass or glass-ceramic material may be coplanar with plastic material 130b in the light guide plate 100. The glass or glass-ceramic portion 130a and the plastic portion 130b may be adhered with each other using suitable optical coupling adhesives known in the industry. The interface of these two or more portions 130a, 140a, 130b may be substantially planar, or may be faceted, paraboloidal, or another suitable geometry or complex shape as desired. As used herein, “coplanar” means that a material (i.e., glass, glass-ceramic, or plastic) shares at least one major face with another material in the same plane. In some embodiments, a distance of less than $0.5*W$ to the first edge 130 can be glass, less than $0.4*W$ to the first edge 130 can be glass, less than $0.3*W$ to the first edge 130 can be glass, less than $0.2*W$ to the first edge 130 can be glass, less than $0.1*W$ to the first edge 130 can be glass, less than $0.05*W$ to the first edge 130 can be glass, or less than $0.01*W$ to the first edge 130 can be glass, and all subranges therebetween. The light injection edge may scatter light within an angle less than 12.8 degrees full width half maximum (FWHM) in transmission. The light injection edge may be obtained by grinding the edge without polishing the light injection edge.

[00026] The glass sheet may further comprise a second edge 140 adjacent to the light injection edge and a third edge opposite the second edge and adjacent to the light injection edge, where the second edge and/or the third edge scatter light within an angle of less than 12.8 degrees FWHM in reflection. The second edge 140 and/or the third edge may have a diffusion angle in reflection that is below 6.4 degrees. It should be noted that while the embodiment depicted in FIG. 1A shows a single edge 130 injected with light, the claimed subject matter should not be so limited as any one or several of the edges of an exemplary embodiment 100 can be injected with light. For example, in some embodiments, the first edge 130 and its opposing edge can both be injected with light (FIG. 1B) and contain corresponding portions 130a of glass material. In other embodiments, the second edge 140 and/or its opposing edge can either or both be injected with light (FIGS. 1C and 1D) and contain corresponding portions 140a of glass material. In yet further embodiments, the second edge 140 and its opposing edge as well as the first edge 130 and its opposing edge can be injected with light (FIG. 1E) and contain corresponding portions 140a, 130a of glass material (e.g., a perimeter portion). In such embodiments, a distance of less than $0.5*H$ to the second edge 140, $0.5*W$ to the first edge 130, and/or the respective opposing edges can be glass; less than $0.4*H$ to the second edge 140, $0.4*W$ to the first edge 130, and/or the

respective opposing edges can be glass; less than $0.3 \cdot H$ to the second edge 140, $0.3 \cdot W$ to the first edge 130, and/or the respective opposing edges can be glass; less than $0.2 \cdot H$ to the second edge 140, $0.2 \cdot W$ to the first edge 130, and/or the respective opposing edges can be glass; less than $0.1 \cdot H$ to the second edge 140, $0.1 \cdot W$ to the first edge 130, and/or the respective opposing edges can be glass; less than $0.05 \cdot H$ to the second edge 140, $0.05 \cdot W$ to the first edge 130, and/or the respective opposing edges can be glass; or less than $0.01 \cdot H$ to the second edge 140, $0.01 \cdot W$ to the first edge 130, and/or the respective opposing edges can be glass less; and all subranges therebetween. Of course, while FIGS. 1A-1E depict a rectangular or square article, such a depiction should not limit the scope of the claims appended herewith as exemplary embodiments may be used in a display device having a large and/or curvilinear widths W or heights H .

[00027] Additional embodiments may inject light at the second edge 140 and its opposing edge rather than the first edge 130 and/or its opposing edge. In similar fashion, the distances of the glass portion of the composite structure can vary. Thicknesses of exemplary display devices can be less than about 10 mm, less than about 9 mm, less than about 8 mm, less than about 7 mm, less than about 6 mm, less than about 5 mm, less than about 4 mm, less than about 3 mm, or less than about 2 mm. In some embodiments, widths of the glass portion of the composite structure (W_G) can be about $0.1 \text{ cm} \leq W_G \leq 10 \text{ cm}$, in some embodiments about $1 \text{ cm} \leq W_G \leq 10 \text{ cm}$, in some embodiments about $2 \text{ cm} \leq W_G$, in some embodiments about $10 \text{ cm} \leq W_G$, and in some embodiments about $1 \text{ cm} \leq W_G \leq 50 \text{ cm}$.

[00028] In various embodiments, the glass composition of the glass portion of the composite sheet may comprise between 60-80 mol% SiO_2 , between 0-20 mol% Al_2O_3 , and between 0-15 mol% B_2O_3 , and less than 50 ppm iron (Fe) concentration. In some embodiments, there may be less than 25 ppm Fe, or in some embodiments the Fe concentration may be about 20 ppm or less. In various embodiments, the thermal conduction of the glass portion of the composite light guide plate 100 may be greater than 0.5 W/m/K. In additional embodiments, the glass portion of the composite sheet may be formed by a polished float glass, a fusion draw process, a slot draw process, a redraw process, or another suitable forming process. The glass portion(s) may be suitably adhered to the plastic portion of the composite sheet by an optically clear adhesive (OCA). Exemplary OCA materials include, but are not limited to, 8142KCL, 8146-X, 8173D, 817xCL, 817cPCL, 821X, 826x, 9483, and other suitable OCAs (tape or liquid). Exemplary plastic materials suitable for use in the plastic portion or section 130b of exemplary composite sheets or light guide plates 100 include, but are not limited to, polymethylmethacrylate (PMMA), polycarbonate (PC),

polyethylene terephthalate (PET), polymethylmethacrylate, polyether ether ketone, polyethylene naphthalate, poly(ethylene succinate), polypropylene, styrene-methacrylate copolymer (MS), cyclic olefin copolymer (COC), and other suitable polymeric materials.

[00029] According to one or more embodiments, the glass portion of the LGP can be made from a glass comprising colorless oxide components selected from the glass formers SiO_2 , Al_2O_3 , and B_2O_3 . The exemplary glass may also include fluxes to obtain favorable melting and forming attributes. Such fluxes include alkali oxides (Li_2O , Na_2O , K_2O , Rb_2O and Cs_2O) and alkaline earth oxides (MgO , CaO , SrO , ZnO and BaO). In one embodiment, the glass contains constituents in the range of 60-80 mol% SiO_2 , in the range of 0-20 mol% Al_2O_3 , in the range of 0-15 mol% B_2O_3 , and in the range of 5 and 20% alkali oxides, alkaline earth oxides, or combinations thereof.

[00030] In some glass compositions described herein, SiO_2 can serve as the basic glass former. In certain embodiments, the concentration of SiO_2 can be greater than 60 mole percent to provide the glass with a density and chemical durability suitable for a display glasses or light guide plate glasses, and a liquidus temperature (liquidus viscosity), which allows the glass to be formed by a downdraw process (e.g., a fusion process). In terms of an upper limit, in general, the SiO_2 concentration can be less than or equal to about 80 mole percent to allow batch materials to be melted using conventional, high volume, melting techniques, e.g., Joule melting in a refractory melter. As the concentration of SiO_2 increases, the 200 poise temperature (melting temperature) generally rises. In various applications, the SiO_2 concentration is adjusted so that the glass composition has a melting temperature less than or equal to $1,750^\circ\text{C}$. In various embodiments, the mol% of SiO_2 may be in the range of about 60% to about 80%, or alternatively in the range of about 66% to about 78%, or in the range of about 72% to about 80%, or in the range of about 65% to about 79%, and all subranges therebetween. In additional embodiments, the mol% of SiO_2 may be between about 70% to about 74%, or between about 74% to about 78%. In some embodiments, the mol% of SiO_2 may be about 72% to 73%. In other embodiments, the mol% of SiO_2 may be about 76% to 77%.

[00031] Al_2O_3 is another glass former used to make the glasses described herein. Higher mole percent Al_2O_3 can improve the glass's annealing point and modulus. In various embodiments, the mol% of Al_2O_3 may be in the range of about 0% to about 20%, or alternatively in the range of about 4% to about 11%, or in the range of about 6% to about 8%, or in the range of about 3% to about 7%, and all subranges therebetween. In additional embodiments, the mol% of Al_2O_3 may be between about 4% to about 10%, or between about

5% to about 8%. In some embodiments, the mol% of Al_2O_3 may be about 7% to 8%. In other embodiments, the mol% of Al_2O_3 may be about 5% to 6%.

[00032] B_2O_3 is both a glass former and a flux that aids melting and lowers the melting temperature. It has an impact on both liquidus temperature and viscosity. Increasing B_2O_3 can be used to increase the liquidus viscosity of a glass. To achieve these effects, the glass compositions of one or more embodiments may have B_2O_3 concentrations that are equal to or greater than 0.1 mole percent; however, some compositions may have a negligible amount of B_2O_3 . As discussed above with regard to SiO_2 , glass durability is very important for display applications. Durability can be controlled somewhat by elevated concentrations of alkaline earth oxides, and significantly reduced by elevated B_2O_3 content. Annealing point decreases as B_2O_3 increases, so it may be helpful to keep B_2O_3 content low. Thus, in various embodiments, the mol% of B_2O_3 may be in the range of about 0% to about 15%, or alternatively in the range of about 0% to about 12%, or in the range of about 0% to about 11%, in the range of about 3% to about 7%, or in the range of about 0% to about 2%, and all subranges therebetween. In some embodiments, the mol% of B_2O_3 may be about 7% to 8%. In other embodiments, the mol% of B_2O_3 may be about 0% to 1%.

[00033] In addition to the glass formers (SiO_2 , Al_2O_3 , and B_2O_3), the glasses described herein also include alkaline earth oxides. In one embodiment, at least three alkaline earth oxides are part of the glass composition, e.g., MgO , CaO , and BaO , and, optionally, SrO . The alkaline earth oxides provide the glass with various properties important to melting, fining, forming, and ultimate use. Accordingly, to improve glass performance in these regards, in one embodiment, the $(\text{MgO}+\text{CaO}+\text{SrO}+\text{BaO})/\text{Al}_2\text{O}_3$ ratio is between 0 and 2.0. As this ratio increases, viscosity tends to increase more strongly than liquidus temperature, and thus it is increasingly difficult to obtain suitably high values for $T_{35k} - T_{liq}$. Thus in another embodiment, ratio $(\text{MgO}+\text{CaO}+\text{SrO}+\text{BaO})/\text{Al}_2\text{O}_3$ is less than or equal to about 2. In some embodiments, the $(\text{MgO}+\text{CaO}+\text{SrO}+\text{BaO})/\text{Al}_2\text{O}_3$ ratio is in the range of about 0 to about 1.0, or in the range of about 0.2 to about 0.6, or in the range of about 0.4 to about 0.6. In detailed embodiments, the $(\text{MgO}+\text{CaO}+\text{SrO}+\text{BaO})/\text{Al}_2\text{O}_3$ ratio is less than about 0.55 or less than about 0.4.

[00034] For certain embodiments of this disclosure, the alkaline earth oxides may be treated as what is in effect a single compositional component. This is because their impact upon viscoelastic properties, liquidus temperatures and liquidus phase relationships are qualitatively more similar to one another than they are to the glass forming oxides SiO_2 , Al_2O_3 and B_2O_3 . However, the alkaline earth oxides CaO , SrO and BaO can form feldspar

minerals, notably anorthite ($\text{CaAl}_2\text{Si}_2\text{O}_8$) and celsian ($\text{BaAl}_2\text{Si}_2\text{O}_8$) and strontium-bearing solid solutions of same, but MgO does not participate in these crystals to a significant degree. Therefore, when a feldspar crystal is already the liquidus phase, a superaddition of MgO may serve to stabilize the liquid relative to the crystal and thus lower the liquidus temperature. At the same time, the viscosity curve typically becomes steeper, reducing melting temperatures while having little or no impact on low-temperature viscosities.

[00035] The inventors have found that the addition of small amounts of MgO may benefit melting by reducing melting temperatures, forming by reducing liquidus temperatures and increasing liquidus viscosity, while preserving high annealing points. In various embodiments, the glass composition comprises MgO in an amount in the range of about 0 mol% to about 10 mol%, or in the range of about 1.0 mol% to about 8.0 mol%, or in the range of about 0 mol% to about 8.72 mol%, or in the range of about 1.0 mol% to about 7.0 mol%, or in the range of about 0 mol% to about 5 mol%, or in the range of about 1 mol% to about 3 mol%, or in the range of about 2 mol% to about 10 mol%, or in the range of about 4 mol% to about 8 mol%, and all subranges therebetween.

[00036] Without being bound by any particular theory of operation, it is believed that calcium oxide present in the glass composition can produce low liquidus temperatures (high liquidus viscosities), high annealing points and moduli, and CTE's in the most desired ranges for display and light guide plate applications. It also contributes favorably to chemical durability, and compared to other alkaline earth oxides, it is relatively inexpensive as a batch material. However, at high concentrations, CaO increases the density and CTE. Furthermore, at sufficiently low SiO_2 concentrations, CaO may stabilize anorthite, thus decreasing liquidus viscosity. Accordingly, in one or more embodiments, the CaO concentration can be between 0 and 6 mol%. In various embodiments, the CaO concentration of the glass composition is in the range of about 0 mol% to about 4.24 mol%, or in the range of about 0 mol% to about 2 mol%, or in the range of about 0 mol% to about 1 mol%, or in the range of about 0 mol% to about 0.5 mol%, or in the range of about 0 mol% to about 0.1 mol%, and all subranges therebetween.

[00037] SrO and BaO can both contribute to low liquidus temperatures (high liquidus viscosities). The selection and concentration of these oxides can be selected to avoid an increase in CTE and density and a decrease in modulus and annealing point. The relative proportions of SrO and BaO can be balanced so as to obtain a suitable combination of physical properties and liquidus viscosity such that the glass can be formed by a downdraw process. In various embodiments, the glass comprises SrO in the range of about 0 to about

8.0 mol%, or between about 0 mol% to about 4.3 mol%, or about 0 to about 5 mol%, 1 mol% to about 3 mol%, or about less than about 2.5 mol%, and all subranges therebetween. In one or more embodiments, the glass comprises BaO in the range of about 0 to about 5 mol%, or between 0 to about 4.3 mol%, or between 0 to about 2.0 mol%, or between 0 to about 1.0 mol%, or between 0 to about 0.5 mol%, and all subranges therebetween.

[00038] In addition to the above components, the glass compositions described herein can include various other oxides to adjust various physical, melting, fining, and forming attributes of the glasses. Examples of such other oxides include, but are not limited to, TiO₂, MnO, Fe₂O₃, ZnO, Nb₂O₅, MoO₃, Ta₂O₅, WO₃, Y₂O₃, La₂O₃ and CeO₂ as well as other rare earth oxides and phosphates. In one embodiment, the amount of each of these oxides can be less than or equal to 2.0 mole percent, and their total combined concentration can be less than or equal to 5.0 mole percent. In some embodiments, the glass composition comprises ZnO in an amount in the range of about 0 to about 3.5 mol%, or about 0 to about 3.01 mol%, or about 0 to about 2.0 mol%, and all subranges therebetween. The glass compositions described herein can also include various contaminants associated with batch materials and/or introduced into the glass by the melting, fining, and/or forming equipment used to produce the glass. The glasses can also contain SnO₂ either as a result of Joule melting using tin-oxide electrodes and/or through the batching of tin containing materials, e.g., SnO₂, SnO, SnCO₃, SnC₂O₂, etc.

[00039] The glass compositions described herein can contain some alkali constituents, e.g., these glasses are not alkali-free glasses. As used herein, an "alkali-free glass" is a glass having a total alkali concentration which is less than or equal to 0.1 mole percent, where the total alkali concentration is the sum of the Na₂O, K₂O, and Li₂O concentrations. In some embodiments, the glass comprises Li₂O in the range of about 0 to about 3.0 mol%, in the range of about 0 to about 3.01 mol%, in the range of about 0 to about 2.0 mol%, in the range of about 0 to about 1.0 mol%, less than about 3.01 mol%, or less than about 2.0 mol%, and all subranges therebetween. In other embodiments, the glass comprises Na₂O in the range of about 3.5 mol% to about 13.5 mol%, in the range of about 3.52 mol% to about 13.25 mol%, in the range of about 4 to about 12 mol%, in the range of about 6 to about 15 mol%, or in the range of about 6 to about 12 mol%, and all subranges therebetween. In some embodiments, the glass comprises K₂O in the range of about 0 to about 5.0 mol%, in the range of about 0 to about 4.83 mol%, in the range of about 0 to about 2.0 mol%, in the range of about 0 to about 1.0 mol%, or less than about 4.83 mol%, and all subranges therebetween.

[00040] In some embodiments, the glass compositions described herein can have one or more or all of the following compositional characteristics: (i) an As₂O₃ concentration of at

most 0.05 mole percent; (ii) an Sb_2O_3 concentration of at most 0.05 mole percent; (iii) a SnO_2 concentration of at most 0.25 mole percent.

[00041] As_2O_3 is an effective high temperature fining agent for display glasses, and in some embodiments described herein, As_2O_3 is used for fining because of its superior fining properties. However, As_2O_3 is poisonous and requires special handling during the glass manufacturing process. Accordingly, in certain embodiments, fining is performed without the use of substantial amounts of As_2O_3 , i.e., the finished glass has at most 0.05 mole percent As_2O_3 . In one embodiment, no As_2O_3 is purposely used in the fining of the glass. In such cases, the finished glass will typically have at most 0.005 mole percent As_2O_3 as a result of contaminants present in the batch materials and/or the equipment used to melt the batch materials.

[00042] Although not as toxic as As_2O_3 , Sb_2O_3 is also poisonous and requires special handling. In addition, Sb_2O_3 raises the density, raises the CTE, and lowers the annealing point in comparison to glasses that use As_2O_3 or SnO_2 as a fining agent. Accordingly, in certain embodiments, fining is performed without the use of substantial amounts of Sb_2O_3 , i.e., the finished glass has at most 0.05 mole percent Sb_2O_3 . In another embodiment, no Sb_2O_3 is purposely used in the fining of the glass. In such cases, the finished glass will typically have at most 0.005 mole percent Sb_2O_3 as a result of contaminants present in the batch materials and/or the equipment used to melt the batch materials.

[00043] Compared to As_2O_3 and Sb_2O_3 fining, tin fining (i.e., SnO_2 fining) is less effective, but SnO_2 is a ubiquitous material that has no known hazardous properties. Also, for many years, SnO_2 has been a component of display glasses through the use of tin oxide electrodes in the Joule melting of the batch materials for such glasses. The presence of SnO_2 in display glasses has not resulted in any known adverse effects in the use of these glasses in the manufacture of liquid crystal displays. However, high concentrations of SnO_2 are not preferred as this can result in the formation of crystalline defects in display glasses. In one embodiment, the concentration of SnO_2 in the finished glass is less than or equal to 0.25 mole percent, in the range of about 0.07 to about 0.11 mol%, in the range of about 0 to about 2 mol%, and all subranges therebetween.

[00044] Tin fining can be used alone or in combination with other fining techniques if desired. For example, tin fining can be combined with halide fining, e.g., bromine fining. Other possible combinations include, but are not limited to, tin fining plus sulfate, sulfide, cerium oxide, mechanical bubbling, and/or vacuum fining. It is contemplated that these other fining techniques can be used alone. In certain embodiments, maintaining the

(MgO+CaO+SrO+BaO)/Al₂O₃ ratio and individual alkaline earth concentrations within the ranges discussed above makes the fining process easier to perform and more effective.

[00045] In various embodiments, the glass may comprise R_xO where R is Li, Na, K, Rb, Cs, and x is 2, or R is Zn, Mg, Ca, Sr or Ba, and x is 1. In some embodiments, R_xO – Al₂O₃ > 0. In other embodiments, 0 < R_xO – Al₂O₃ < 15. In some embodiments, R_xO/Al₂O₃ is between 0 and 10, between 0 and 5, greater than 1, or between 1.5 and 3.75, or between 1 and 6, or between 1.1 and 5.7, and all subranges therebetween. In other embodiments, 0 < R_xO – Al₂O₃ < 15. In further embodiments, x = 2 and R₂O – Al₂O₃ < 15, < 5, < 0, between -8 and 0, or between -8 and -1, and all subranges therebetween. In additional embodiments, R₂O – Al₂O₃ < 0. In yet additional embodiments, x=2 and R₂O – Al₂O₃ – MgO > -10, > -5, between 0 and -5, between 0 and -2, > -2, between -5 and 5, between -4.5 and 4, and all subranges therebetween. In further embodiments, x = 2 and R_xO/Al₂O₃ is between 0 and 4, between 0 and 3.25, between 0.5 and 3.25, between 0.95 and 3.25, and all subranges therebetween. These ratios play significant roles in establishing the manufacturability of the glass article as well as determining its transmission performance. For example, glasses having R_xO – Al₂O₃ approximately equal to or larger than zero will tend to have better melting quality but if R_xO – Al₂O₃ becomes too large of a value, then the transmission curve will be adversely affected. Similarly, if R_xO – Al₂O₃ (e.g., R₂O – Al₂O₃) is within a given range as described above then the glass will likely have high transmission in the visible spectrum while maintaining meltability and suppressing the liquidus temperature of a glass. Similarly, the R₂O – Al₂O₃ – MgO values described above may also help suppress the liquidus temperature of the glass.

[00046] In one or more embodiments and as noted above, exemplary glasses can have low concentrations of elements that produce visible absorption when in a glass matrix. Such absorbers include transition elements such as Ti, V, Cr, Mn, Fe, Co, Ni and Cu, and rare earth elements with partially-filled f-orbitals, including Ce, Pr, Nd, Sm, Eu, Tb, Dy, Ho, Er and Tm. Of these, the most abundant in conventional raw materials used for glass melting are Fe, Cr and Ni. Iron is a common contaminant in sand, the source of SiO₂, and is a typical contaminant as well in raw material sources for aluminum, magnesium and calcium. Chromium and nickel are typically present at low concentration in normal glass raw materials, but can be present in various ores of sand and must be controlled at a low concentration. Additionally, chromium and nickel can be introduced via contact with stainless steel, e.g., when raw material or cullet is jaw-crushed, through erosion of steel-lined mixers or screw feeders, or unintended contact with structural steel in the melting unit itself.

The concentration of iron in some embodiments can be specifically less than 50ppm, more specifically less than 40ppm, or less than 25 ppm, and the concentration of Ni and Cr can be specifically less than 5 ppm, and more specifically less than 2ppm. In further embodiments, the concentration of all other absorbers listed above may be less than 1ppm for each. In various embodiments the glass comprises 1 ppm or less of Co, Ni, and Cr, or alternatively less than 1 ppm of Co, Ni, and Cr. In various embodiments, the transition elements (V, Cr, Mn, Fe, Co, Ni and Cu) may be present in the glass at 0.1 wt% or less. In some embodiments, the concentration of Fe can be < about 50 ppm, < about 40 ppm, < about 30 ppm, < about 20 ppm, or < about 10 ppm. In other embodiments, $\text{Fe} + 30\text{Cr} + 35\text{Ni} < \text{about } 60 \text{ ppm}$, < about 50 ppm, < about 40 ppm, < about 30 ppm, < about 20 ppm, or < about 10 ppm.

[00047] Even in the case that the concentrations of transition metals are within the above described ranges, there can be matrix and redox effects that result in undesired absorption. As an example, it is well-known to those skilled in the art that iron occurs in two valences in glass, the +3 or ferric state, and the +2 or ferrous state. In glass, Fe^{3+} produces absorptions at approximately 380, 420 and 435 nm, whereas Fe^{2+} absorbs mostly at IR wavelengths. Therefore, according to one or more embodiments, it may be desirable to force as much iron as possible into the ferrous state to achieve high transmission at visible wavelengths. One non-limiting method to accomplish this is to add components to the glass batch that are reducing in nature. Such components could include carbon, hydrocarbons, or reduced forms of certain metalloids, e.g., silicon, boron or aluminum. However it is achieved, if iron levels were within the described range, according to one or more embodiments, at least 10% of the iron in the ferrous state and more specifically greater than 20% of the iron in the ferrous state, improved transmissions can be produced at short wavelengths. Thus, in various embodiments, the concentration of iron in the glass produces less than 1.1 dB/500 mm of attenuation in the glass sheet. Further, in various embodiments, the concentration of $\text{V} + \text{Cr} + \text{Mn} + \text{Fe} + \text{Co} + \text{Ni} + \text{Cu}$ produces 2 dB/500 mm or less of light attenuation in the glass sheet when the ratio $(\text{Li}_2\text{O} + \text{Na}_2\text{O} + \text{K}_2\text{O} + \text{Rb}_2\text{O} + \text{Cs}_2\text{O} + \text{MgO} + \text{ZnO} + \text{CaO} + \text{SrO} + \text{BaO}) / \text{Al}_2\text{O}_3$ for borosilicate glass is between 0 and 4.

[00048] The valence and coordination state of iron in a glass matrix can also be affected by the bulk composition of the glass. For example, iron redox ratio has been examined in molten glasses in the system $\text{SiO}_2 - \text{K}_2\text{O} - \text{Al}_2\text{O}_3$ equilibrated in air at high temperature. It was found that the fraction of iron as Fe^{3+} increases with the ratio $\text{K}_2\text{O} / (\text{K}_2\text{O} + \text{Al}_2\text{O}_3)$, which in practical terms will translate to greater absorption at short wavelengths.

In exploring this matrix effect, it was discovered that the ratios $(\text{Li}_2\text{O} + \text{Na}_2\text{O} + \text{K}_2\text{O} + \text{Rb}_2\text{O} + \text{Cs}_2\text{O}) / \text{Al}_2\text{O}_3$ and $(\text{MgO} + \text{CaO} + \text{ZnO} + \text{SrO} + \text{BaO}) / \text{Al}_2\text{O}_3$ can also be important for maximizing transmission in borosilicate glasses. Thus, for the R_xO ranges described above, transmission at exemplary wavelengths can be maximized for a given iron content. This is due in part to the higher proportion of Fe^{2+} , and partially to matrix effects associated with the coordination environment of iron.

[00049] Attenuation of light in a glass or polymer LGP can be determined from the relationship provided below:

$$\alpha = 10 \cdot (-\log T) \quad (1)$$

where α (alpha) is absorbance in units of dB, and T is the transmittance through the glass sheet as measured in air (including Fresnel reflection losses which correspond to about 4% per at the glass-air interfaces). The terms $\alpha_{(\lambda)}$ and $T_{(\lambda)}$ refer to the absorbance and transmittance at wavelength λ (lambda) in nm of the LGP, respectively. The terms $\alpha(\text{glass})$ and $T(\text{glass})$ refer to the absorbance of the glass and transmittance of the glass, respectively. The terms $\alpha(\text{polymer})$ and $T(\text{polymer})$ refer to the absorbance of the polymer and transmittance of the polymer, respectively. The terms α_{INT} and T_{INT} refer to the internal absorbance and internal transmittance of the LGP, respectively.

[00050] Attenuation of light per unit length in an LGP section can be determined using the relationship below:

$$\Omega = \alpha / \text{LGP distance} \quad (2)$$

where Ω (omega) is in units of dB/cm, and LGP distance is the width in cm (that is, the width W_{1G} and W_{2G} of the glass portions 130a or 140a from edge 130 and 140, respectively of LGP 110, as shown in figures 1A and 1C) through which the light is transmitted. The terms W_G and W_P refer to the width of the glass and polymer portions, respectively, of the LGP. The terms W_{1P} and W_{2P} in Figures 1A and 1C refer to the width of the polymer portions, respectively, of LGP 110. It should be noted that such widths are not illustrated in Figures 1B, 1D and 1E solely for clarity in the respective figures; however, each of the glass and polymer portions in these figures possess such widths. The terms $\Omega(\text{glass})$ and $\Omega(\text{polymer})$ refer to the absorbance per unit length in dB/cm of the glass and polymer, respectively. In some

embodiments $0.1 \text{ cm} \leq W_G \leq 10 \text{ cm}$, in some embodiments $1 \text{ cm} \leq W_G \leq 10 \text{ cm}$, in some embodiments $2 \text{ cm} \leq W_G$, in some embodiments $10 \text{ cm} \leq W_G$, and in some embodiments $1 \text{ cm} \leq W_G \leq 50 \text{ cm}$. In some embodiments, $\Omega(\text{glass}) \leq 0.7 \text{ dB/cm}$ at 450 nm and $\Omega(\text{glass}) \leq 0.5 \text{ dB/cm}$ at 550 nm, or $\Omega(\text{glass}) \leq 0.7 \text{ dB/cm}$ at 630 nm. In some embodiments, $\Omega(\text{glass}) \leq 0.35 \text{ dB/cm}$ at 450 nm and $\Omega(\text{glass}) \leq 0.25 \text{ dB/cm}$ at 550 nm, or $\Omega(\text{glass}) \leq 0.35 \text{ dB/cm}$ at 630 nm. In some embodiments, $\Omega(\text{glass}) \leq 0.14 \text{ dB/cm}$ at 450 nm and $\Omega(\text{glass}) \leq 0.10 \text{ dB/cm}$ at 550 nm, or $\Omega(\text{glass}) \leq 0.14 \text{ dB/cm}$ at 630 nm. In some embodiments, $\Omega(\text{glass}) \leq 0.07 \text{ dB/cm}$ at 450 nm and $\Omega(\text{glass}) \leq 0.05 \text{ dB/cm}$ at 550 nm, or $\Omega(\text{glass}) \leq 0.07 \text{ dB/cm}$ at 630 nm. In some embodiments, $\Omega(\text{glass}) \leq 0.014 \text{ dB/cm}$ at 450 nm and $\Omega(\text{glass}) \leq 0.010 \text{ dB/cm}$ at 550 nm, or $\Omega(\text{glass}) \leq 0.014 \text{ dB/cm}$ at 630 nm. In some embodiments, $1 \text{ cm} \leq W_G \leq 10 \text{ cm}$ and $0.007 \text{ dB/cm} \leq \Omega(\text{glass}) \leq 0.7 \text{ dB/cm}$ for all wavelengths greater than or equal to 450 nm to less than or equal to 630 nm. In some embodiments $1 \text{ cm} \leq W_G \leq 10 \text{ cm}$ and $0.35 \text{ dB} \leq \alpha(\text{glass}) \leq 0.7 \text{ dB}$ for all wavelengths greater than or equal to 450 nm to less than or equal to 630 nm.

[00051] FIG. 3 is a graph showing an expected coupling (without Fresnel losses) as a function of distance between the LGP and LED for a 2mm thick LED's coupled into a 2mm thick LGP. With reference to FIG. 3, light injection in an exemplary embodiment usually involves placing the LGP in direct proximity to one or more light emitting diodes (LEDs). According to one or more embodiments, efficient coupling of light from an LED to the LGP involves using LED with a thickness or height that is less than or equal to the thickness of the sheet. Thus, according to one or more embodiments, the distance from the LED to the LGP can be controlled to improve LED light injection. FIG. 3 shows the expected coupling (without Fresnel losses) as a function of that distance and considering 2 mm height LED's coupled into a 2 mm thick LGP. According to FIG. 3, the distance should be < about 0.5mm to keep coupling > about 80%. When plastic such as PMMA is used as a conventional LGP material, putting the LGP in physical contact with the LED's is somewhat problematic. First, a minimum distance is needed to let the material expand. Also LEDs tend to heat up significantly and, in case of physical contact, PMMA can get close to its Tg (105° C for PMMA). The temperature elevation that was measured when putting PMMA in contact with LED's was about 50°C close by the LEDs. Thus for PMMA LGP, a minimum air gap is needed which degrades the coupling as shown in FIG. 3. According to embodiments of the subject matter in which composite glass and plastic LGPs are utilized, heating the glass is not a problem since Tg (glass transition temperature) of glass is much higher and physical contact

may actually be an advantage since glass has a thermal conduction coefficient that is large enough to make the LGP to be one additional heat dissipation mechanism.

[00052] FIG. 4 is a pictorial illustration of a coupling mechanism from an LED to a composite LGP. With reference to FIG. 5, assuming that the LED is close to a lambertian emitter and assuming the glass index of refraction is about 1.5, the angle α will stay smaller than 41.8 degrees (as in $(1/1.5)$) and the angle β will stay larger than 48.2 degrees ($90 - \alpha$). Since total internal reflection (TIR) angle is about 41.8 degrees, this means that all the light remains internal to the guide and coupling is close to 100%. At the level of the LED injection, the injection face may cause some diffusion which will increase the angle at which light is propagating into the LGP. In the event this angle becomes larger than the TIR angle, light may leak out of the LGP resulting in coupling losses. However, the condition for not introducing significant losses is that the angle in which light gets scattered should be less than $48.2 - 41.8 = \pm 6.4$ degrees (scattering angle < 12.8 degrees). Thus, according to one or more embodiments, a plurality of the edges of the LGP may have a mirror polish to improve LED coupling and TIR. In some embodiments, three of the four edges have a mirror polish. Of course, these angles are exemplary only and should not limit the scope of the claims appended herewith as exemplary scattering angles can be < 20 degrees, < 19 degrees, < 18 degrees, < 17 degrees, < 16 degrees, < 14 degrees, < 13 degrees, < 12 degrees, < 11 degrees, or < 10 degrees. Further, exemplary diffusion angles in reflection can be, but are not limited to, < 15 degrees, < 14 degrees, < 13 degrees, < 12 degrees, < 11 degrees, < 10 degrees, < 9 degrees, < 8 degrees, < 7 degrees, < 6 degrees, < 5 degrees, < 4 degrees, or < 3 degrees.

[00053] In some embodiments, the back side of the LGP glass and or/plastic portions may comprise a heat sink to further dissipate heat away from the LGP. Exemplary heat sinks can comprise a metal or other suitable thermally conductive material. Non-limiting examples include metal filled polymers and metal films, iron and its alloys, aluminum and its alloys, silver and its alloys, stainless steel alloys, and the like. Some exemplary heat sinks may also include thermally conductive materials having a thermal conductivities of greater than 1 W(m K), in some embodiments greater than or equal to 10 W(m K), in some embodiments greater than or equal to 40 W(m K), in some embodiments greater than or equal to 100 W(m K). In some embodiments the thickness of the thermally conductive material is greater than 10 microns, in other embodiments greater than or equal to 100 microns, in other embodiments greater than or equal to 500 microns, and in other embodiments greater than or equal to 500 microns and less than 5 mm.

[00054] FIG. 5 is a graph showing an expected angular energy distribution calculated from surface topology. With reference to FIG. 5, the typical texture of a grinded only edge is illustrated where roughness amplitude is relatively high (on the order of 1 nm) but special frequencies are relatively low (on the order of 20 microns) resulting in a low scattering angle. Further, this figure illustrates the expected angular energy distribution calculated from the surface topology. As can be seen, scattering angle can be much less than 12.8 degrees full width half maximum (FWHM).

[00055] In terms of surface definition, a surface can be characterized by a local slope distribution $\theta(x,y)$ that can be calculated, for instance, by taking the derivative of the surface profile. The angular deflection in the glass can be calculated, in first approximation as :

$$\theta'(x,y) = \theta(x,y)/n$$

Therefore, the condition on the surface roughness is $\theta(x,y) < n * 6.4$ degrees with TIR at the 2 adjacent edges.

[00056] LCD panel rigidity

[00057] One attribute of LCD panels is the overall thickness. In conventional attempts to make thinner structures, lack of sufficient stiffness has become a serious problem. Stiffness, however, can be increased with an exemplary composite LGP since the elastic modulus of glass is considerably larger than that of PMMA. In some embodiments, to obtain a maximum benefit from a stiffness point of view, all elements of the panel can be bonded together at the edge.

[00058] FIG. 6 is a cross sectional illustration of an exemplary LCD panel with a LGP in accordance with one or more embodiments. With reference to FIG. 6, an exemplary embodiment of a panel structure 500 is provided. The structure comprises an LGP 100 mounted on a back plate 550 through which light can travel and be redirected toward the LCD or an observer. An exemplary LGP 100 can comprise any of the embodiments described above and with reference to FIGS. 1A-1E illustrating glass or glass-ceramic portions 130a, 140a and plastic portions 130b. For clarity only, a single edge glass portion 130a is illustrated in FIG. 6, but such a depiction should not limit the scope of the claims appended herewith. A structural element 555 may affix the LGP 100 to the back plate 550, and create a gap between the back face of the LGP and a face of the back plate. A reflective and/or diffusing film 540 may be positioned between the back face of the LGP 100 and the back plate 550 to send recycled light back through the LGP 100. A plurality of light sources 200 (e.g., LEDs, organic light emitting diodes (OLEDs), or cold cathode fluorescent lamps (CCFLs)) may be positioned adjacent to the light injection edge 130 of the LGP, where the

LEDs have the same width as the thickness of the LGP 100, and are at the same height as the LGP 100. These light sources 200 may be coupled in some embodiments to the LGP 100 by a suitable adhesive 595 such as, but not limited to, optically clear adhesives or the like. In other embodiments, the suitable adhesive 595 may be replaced with an air gap (not shown). Conventional LCDs may employ LEDs or CCFLs packaged with color converting phosphors to produce white light. One or more backlight film(s) 570 may be positioned adjacent the front face of the LGP 100. An LCD panel 580 may also be positioned above the front face of the LGP 100 with a structural element 585, and the backlight film(s) 570 may be located in the gap between the LGP 100 and LCD panel 580. Light from the LGP 100 can then pass through the film 570, which can backscatter high angle light and reflect low angle light back toward the reflector film 540 for recycling and may serve to concentrate light in the forward direction (e.g., toward the user). A bezel 520 or other structural member may hold the layers of the assembly in place. A liquid crystal layer (not shown) may be used and may comprise an electro-optic material, the structure of which rotates upon application of an electric field, causing a polarization rotation of any light passing through it. Other optical components can include, e.g., prism films, polarizers, or TFT arrays, to name a few. According to various embodiments, the angular light filters disclosed herein can be paired with a transparent composite light guide plate in a transparent display device. In some embodiments, the LGP can be bonded to the structure (using optically clear adhesive OCA or pressure sensitive adhesive PSA) where the LGP is placed in optical contact with some of the structural elements of the panel. In other words, some of the light may leak out of the composite light guide through the adhesive. This leaked light can become scattered or absorbed by those structural elements. As explained above, the first edge where the LEDs are coupled into the LGP and the two adjacent edges where the light needs to be reflected in TIR can avoid this problem if properly prepared.

[00059] Exemplary widths and heights of the LGP generally depend upon the size of the respective LCD panel. It should be noted that embodiments of the present subject matter are applicable to any size LCD panel whether small (<40" diagonal) or large (>40" diagonal) displays.

[00060] Color shift compensation

[00061] In prior glasses although decreasing iron concentration minimized absorption and yellow shift, it was difficult to eliminate it completely. The Δx , Δy in the measured for PMMA for a propagation distance of about 700mm was 0.0021 and 0.0063. In exemplary

glasses having the compositional ranges described herein, it was < 0.015 and in exemplary embodiments was less than 0.0021, and less than 0.0063. For example, in some embodiments, the color shift was measured as 0.007842 and in other embodiments was measured as 0.005827. To address residual color shift, several exemplary solutions may be implemented. In one embodiment, light guide blue painting can be employed. By blue painting the light guide, one can artificially increase absorption in red and green and increase light extraction in blue. Accordingly, knowing how much differential color absorption exists, a blue paint pattern can be back calculated and applied that can compensate for color shift. In one or more embodiments, shallow surface scattering features can be employed to extract light with an efficiency that depends on the wavelength. As an example, a square grating has a maximum of efficiency when the optical path difference equals half of the wavelength. Accordingly, exemplary textures can be used to preferentially extract blue and can be added to the main light extraction texture. In additional embodiments, image processing can also be utilized. For example, an image filter can be applied that will attenuate blue close to the edge where light gets injected. This may require shifting the color of the LEDs themselves to keep the right white color. In further embodiments, pixel geometry can be used to address color shift by adjusting the surface ratio of the RGB pixels in the panel and increasing the surface of the blue pixels far away from the edge where the light gets injected. In exemplary embodiments, the glass material of the composite light guide plate 100 or sheet can have a color shift substantially similar to or the same as the plastic material of the composite light guide plate 100.

[00062] Examples and glass compositions

[00063] Further to the exemplary compositions the attenuation impact of each element may be estimated by identifying the wavelength in the visible where it attenuates most strongly. In examples shown in Table 1 below, the coefficients of absorption of the various transition metals have been experimentally determined in relation to the concentrations of Al_2O_3 to R_xO (however, only the modifier Na_2O has been shown below for brevity).

TABLE 1

		dB/ppm/500mm	
	$\text{Al}_2\text{O}_3 > \text{Na}_2\text{O}$	$\text{Al}_2\text{O}_3 = \text{Na}_2\text{O}$	$\text{Al}_2\text{O}_3 < \text{Na}_2\text{O}$
V	0.119	0.109	0.054
Cr	2.059	1.869	9.427
Mn	0.145	0.06	0.331
Fe	0.336	0.037	0.064

Co	1.202	2.412	3.7
Ni	0.863	0.617	0.949
Cu	0.108	0.092	0.11

[00064] With the exception of V (vanadium), a minimum attenuation is found for glasses with concentrations of $\text{Al}_2\text{O}_3 = \text{Na}_2\text{O}$, or more generally for $\text{Al}_2\text{O}_3 \sim \text{R}_x\text{O}$. In various instances the transition metals may assume two or more valences (e.g., Fe can be both +2 and +3), so to some extent the redox ratio of these various valences may be impacted by the bulk composition. Transition metals respond differently to what are known as “crystal field” or “ligand field” effects that arise from interactions of the electrons in their partially-filled d-orbital with the surrounding anions (oxygen, in this case), particularly if there are changes in the number of anion nearest neighbors (also referred to as coordination number). Thus, it is likely that both redox ratio and crystal field effects contribute to this result.

[00065] The coefficients of absorption of the various transition metals may also be utilized to determine the attenuation of the glass composition over a path length in the visible spectrum (i.e., between 380 and 700nm), as shown in Table 2 below.

TABLE 2

$\text{Al}_2\text{O}_3 - \text{R}_x\text{O} = 4$	$0.119\text{V} + 2.059\text{Cr} + 0.145\text{Mn} + 0.336\text{Fe} + 1.202\text{Co} + 0.863\text{Ni} + 0.108\text{Cu} < 2$
$\text{Al}_2\text{O}_3 \sim \text{R}_x\text{O} = 0$	$0.109\text{V} + 1.869\text{Cr} + 0.06\text{Mn} + 0.037\text{Fe} + 2.412\text{Co} + 0.617\text{Ni} + 0.092\text{Cu} < 2$
$\text{Al}_2\text{O}_3 < \text{R}_x\text{O} = -4$	$0.054\text{V} + 9.427\text{Cr} + 0.331\text{Mn} + 0.064\text{Fe} + 3.7\text{Co} + 0.949\text{Ni} + 0.11\text{Cu} < 2$

[00066] Of course the values identified in Table 2 are exemplary only should not limit the scope of the claims appended herewith. For example, it was also unexpectedly discovered that a high transmittance glass could be obtained when $\text{Fe} + 30\text{Cr} + 35\text{Ni} < 60$ ppm. In some embodiments, the concentration of Fe can be $< \text{about } 50 \text{ ppm}$, $< \text{about } 40 \text{ ppm}$, $< \text{about } 30 \text{ ppm}$, $< \text{about } 20 \text{ ppm}$, or $< \text{about } 10 \text{ ppm}$. In other embodiments, $\text{Fe} + 30\text{Cr} + 35\text{Ni} < \text{about } 50 \text{ ppm}$, $< \text{about } 40 \text{ ppm}$, $< \text{about } 30 \text{ ppm}$, $< \text{about } 20 \text{ ppm}$, or $< \text{about } 10 \text{ ppm}$.

[00067] Tables 3 and 4 provide some exemplary non-limiting examples of glasses prepared for embodiments of the present subject matter.

TABLE 3

	wt%	mol%
SiO_2	66.72	77.22
SiO_2 (diff)	67.003	
Al_2O_3	12	7.62
B_2O_3	8.15	7.58

Li ₂ O	0	0
Na ₂ O	7.73	8.08
K ₂ O	0.013	0.01
ZnO	0	0
MgO	1.38	2.22
CaO	0.029	0.03
SrO	3.35	2.09
BaO		0.08
SnO ₂	0.176	0.08
Fe ₂ O ₃	0.12	

TABLE 4

	wt%	mol%
SiO ₂	74.749	76.37
SiO ₂ (diff)	74.847	
Al ₂ O ₃	8.613	5.18
B ₂ O ₃	0	0
Li ₂ O	0	0
Na ₂ O	11.788	11.66
K ₂ O	0.003	0
ZnO	0	0
MgO	4.344	6.61
CaO	0.027	0.03
SrO	0	0
BaO	0	0
SnO ₂	0.24	0.1
Fe ₂ O ₃	0.128	

[00068] Exemplary compositions as heretofore described can thus be used to achieve a strain point ranging from about 525 °C to about 575 °C, from about 540 °C to about 570 °C, or from about 545 °C to about 565 °C and all subranges therebetween. In one embodiment, the strain point is about 547 °C, and in another embodiment, the strain point is about 565 °C. An exemplary annealing point can range from about 575 °C to about 625 °C, from about 590 °C to about 620 °C, and all subranges therebetween. In one embodiment, the annealing point is about 593 °C, and in another embodiment, the annealing point is about 618 °C. An exemplary softening point of a glass ranges from about 800 °C to about 890 °C, from about 820 °C to about 880 °C, or from about 835 °C to about 875 °C and all subranges therebetween. In one embodiment, the softening point is about 836.2 °C, in another

embodiment, the softening point is about 874.7 °C. The density of exemplary glass compositions can range from about 1.95 gm/cc @ 20 C to about 2.7 gm/cc @ 20 C, from about 2.1 gm/cc @ 20 C to about 2.4 gm/cc @ 20 C, or from about 2.3 gm/cc @ 20 C to about 2.4 gm/cc @ 20 C and all subranges therebetween. In one embodiment the density is about 2.389 gm/cc @ 20 C, and in another embodiment the density is about 2.388 gm/cc @ 20 C. CTEs (0-300 °C) for exemplary embodiments can range from about $30 \times 10^{-7}/^{\circ}\text{C}$ to about $95 \times 10^{-7}/^{\circ}\text{C}$, from about $50 \times 10^{-7}/^{\circ}\text{C}$ to about $80 \times 10^{-7}/^{\circ}\text{C}$, or from about $55 \times 10^{-7}/^{\circ}\text{C}$ to about $70 \times 10^{-7}/^{\circ}\text{C}$ and all subranges therebetween. In one embodiment the CTE is about $55.7 \times 10^{-7}/^{\circ}\text{C}$ and in another embodiment the CTE is about $69 \times 10^{-7}/^{\circ}\text{C}$.

[00069] Certain embodiments and compositions described herein have provided a transmission from 400-700 nm greater than 90%, greater than 91%, greater than 92%, greater than 93%, greater than 94%, and even greater than 95%. Thus, exemplary embodiments described herein can have a transmittance at 450 nm with 500 mm in length of greater than 85%, greater than 90%, greater than 91%, greater than 92%, greater than 93%, greater than 94%, and even greater than 95%. Exemplary embodiments described herein can also have a transmittance at 550 nm with 500 mm in length of greater than 90%, greater than 91%, greater than 92%, greater than 93%, greater than 94%, and even greater than 96%. Further embodiments described herein can have a transmittance at 630 nm with 500 mm in length of greater than 85%, greater than 90%, greater than 91%, greater than 92%, greater than 93%, greater than 94%, and even greater than 95%. In some embodiments, the transmittance of the glass material of the light guide plate 100 is substantially similar to or the same as the transmittance of the plastic material of the light guide plate at the same wavelengths.

[00070] In one or more embodiments, the LGP has a width of at least about 1270 mm and a thickness of between about 0.5 mm and about 3.0 mm, wherein the transmittance of the LGP is at least 80% per 500 mm. In various embodiments, the thickness of the LGP is between about 1 mm and about 8 mm, and the width of the plate is between about 1100 mm and about 1300 mm.

[00071] In one or more embodiments, the glass portions of the LGP can be strengthened. For example, certain characteristics, such as a moderate compressive stress (CS), high depth of compressive layer (DOL), and/or moderate central tension (CT) can be provided in an exemplary glass used for a LGP. One exemplary process includes chemically strengthening the glass by preparing a glass sheet capable of ion exchange. The glass sheet can then be subjected to an ion exchange process, and thereafter the glass sheet can be subjected to an anneal process if necessary. Of course, if the CS and DOL of the glass sheet

are desired at the levels resulting from the ion exchange step, then no annealing step is required. In other embodiments, an acid etching process can be used to increase the CS on appropriate glass surfaces. The ion exchange process can involve subjecting the glass sheet to a molten salt bath including KNO_3 , preferably relatively pure KNO_3 for one or more first temperatures within the range of about 400 - 500 °C and/or for a first time period within the range of about 1-24 hours, such as, but not limited to, about 8 hours. It is noted that other salt bath compositions are possible and would be within the skill level of an artisan to consider such alternatives. Thus, the disclosure of KNO_3 should not limit the scope of the claims appended herewith. Such an exemplary ion exchange process can produce an initial CS at the surface of the glass sheet, an initial DOL into the glass sheet, and an initial CT within the glass sheet. Annealing can then produce a final CS, final DOL and final CT as desired.

[00072] EXAMPLES

[00073] The following examples are set forth below to illustrate the methods and results according to the disclosed subject matter. These examples are not intended to be inclusive of all embodiments of the subject matter disclosed herein, but rather to illustrate representative methods and results. These examples are not intended to exclude equivalents and variations of the present disclosure which are apparent to one skilled in the art.

[00074] Efforts have been made to ensure accuracy with respect to numbers (e.g., amounts, temperature, etc.) but some errors and deviations should be accounted for. Unless indicated otherwise, temperature is in °C or is at ambient temperature, and pressure is at or near atmospheric. The compositions themselves are given in mole percent on an oxide basis and have been normalized to 100%. There are numerous variations and combinations of reaction conditions, e.g., component concentrations, temperatures, pressures and other reaction ranges and conditions that can be used to optimize the product purity and yield obtained from the described process. Only reasonable and routine experimentation will be required to optimize such process conditions.

[00075] The glass properties set forth herein and in Table 5 below were determined in accordance with techniques conventional in the glass art. Thus, the linear coefficient of thermal expansion (CTE) over the temperature range 25-300°C is expressed in terms of $\times 10^{-7}/^\circ\text{C}$ and the annealing point is expressed in terms of °C. These were determined from fiber elongation techniques (ASTM references E228-85 and C336, respectively). The density in terms of grams/cm³ was measured via the Archimedes method (ASTM C693). The melting temperature in terms of °C (defined as the temperature at which the glass melt demonstrates a

viscosity of 200 poises) was calculated employing a Fulcher equation fit to high temperature viscosity data measured via rotating cylinders viscometry (ASTM C965-81).

[00076] The liquidus temperature of the glass in terms of °C was measured using the standard gradient boat liquidus method of ASTM C829-81. This involves placing crushed glass particles in a platinum boat, placing the boat in a furnace having a region of gradient temperatures, heating the boat in an appropriate temperature region for 24 hours, and determining by means of microscopic examination the highest temperature at which crystals appear in the interior of the glass. More particularly, the glass sample is removed from the Pt boat in one piece, and examined using polarized light microscopy to identify the location and nature of crystals which have formed against the Pt and air interfaces, and in the interior of the sample. Because the gradient of the furnace is very well known, temperature vs. location can be well estimated, within 5-10 °C. The temperature at which crystals are observed in the internal portion of the sample is taken to represent the liquidus of the glass (for the corresponding test period). Testing is sometimes carried out at longer times (e.g. 72 hours), to observe slower growing phases. The liquidus viscosity in poises was determined from the liquidus temperature and the coefficients of the Fulcher equation. If included, Young's modulus values in terms of GPa were determined using a resonant ultrasonic spectroscopy technique of the general type set forth in ASTM E1875-00e1.

[00077] The exemplary glasses of the tables herein were prepared using a commercial sand as a silica source, milled such that 90% by weight passed through a standard U.S. 100 mesh sieve. Alumina was the alumina source, periclase was the source for MgO, limestone the source for CaO, strontium carbonate, strontium nitrate or a mix thereof was the source for SrO, barium carbonate was the source for BaO, and tin (IV) oxide was the source for SnO₂. The raw materials were thoroughly mixed, loaded into a platinum vessel suspended in a furnace heated by silicon carbide glowbars, melted and stirred for several hours at temperatures between 1600 and 1650°C to ensure homogeneity, and delivered through an orifice at the base of the platinum vessel. The resulting patties of glass were annealed at or near the annealing point, and then subjected to various experimental methods to determine physical, viscous and liquidus attributes.

[00078] These methods are not unique, and the glasses of the tables herein can be prepared using standard methods well-known to those skilled in the art. Such methods include a continuous melting process, such as would be performed in a continuous melting process, wherein the melter used in the continuous melting process is heated by gas, by electric power, or combinations thereof.

[00079] Raw materials appropriate for producing exemplary glasses include commercially available sands as sources for SiO_2 ; alumina, aluminum hydroxide, hydrated forms of alumina, and various aluminosilicates, nitrates and halides as sources for Al_2O_3 ; boric acid, anhydrous boric acid and boric oxide as sources for B_2O_3 ; periclase, dolomite (also a source of CaO), magnesia, magnesium carbonate, magnesium hydroxide, and various forms of magnesium silicates, aluminosilicates, nitrates and halides as sources for MgO ; limestone, aragonite, dolomite (also a source of MgO), wolastonite, and various forms of calcium silicates, aluminosilicates, nitrates and halides as sources for CaO ; and oxides, carbonates, nitrates and halides of strontium and barium. If a chemical fining agent is desired, tin can be added as SnO_2 , as a mixed oxide with another major glass component (e.g., CaSnO_3), or in oxidizing conditions as SnO , tin oxalate, tin halide, or other compounds of tin known to those skilled in the art.

[00080] The glasses in the tables herein can contain SnO_2 as a fining agent, but other chemical fining agents could also be employed to obtain glass of sufficient quality for display applications. For example, exemplary glasses could employ any one or combinations of As_2O_3 , Sb_2O_3 , CeO_2 , Fe_2O_3 , and halides as deliberate additions to facilitate fining, and any of these could be used in conjunction with the SnO_2 chemical fining agent shown in the examples. Of these, As_2O_3 and Sb_2O_3 are generally recognized as hazardous materials, subject to control in waste streams such as might be generated in the course of glass manufacture or in the processing of TFT panels. It is therefore desirable to limit the concentration of As_2O_3 and Sb_2O_3 individually or in combination to no more than 0.005 mol%.

[00081] In addition to the elements deliberately incorporated into exemplary glasses, nearly all stable elements in the periodic table are present in glasses at some level, either through low levels of contamination in the raw materials, through high-temperature erosion of refractories and precious metals in the manufacturing process, or through deliberate introduction at low levels to fine tune the attributes of the final glass. For example, zirconium may be introduced as a contaminant via interaction with zirconium-rich refractories. As a further example, platinum and rhodium may be introduced via interactions with precious metals. As a further example, iron may be introduced as a tramp in raw materials, or deliberately added to enhance control of gaseous inclusions. As a further example, manganese may be introduced to control color or to enhance control of gaseous inclusions.

[00082] Hydrogen is inevitably present in the form of the hydroxyl anion, OH^- , and its presence can be ascertained via standard infrared spectroscopy techniques. Dissolved

hydroxyl ions significantly and nonlinearly impact the annealing point of exemplary glasses, and thus to obtain the desired annealing point it may be necessary to adjust the concentrations of major oxide components so as to compensate. Hydroxyl ion concentration can be controlled to some extent through choice of raw materials or choice of melting system. For example, boric acid is a major source of hydroxyls, and replacing boric acid with boric oxide can be a useful means to control hydroxyl concentration in the final glass. The same reasoning applies to other potential raw materials comprising hydroxyl ions, hydrates, or compounds comprising physisorbed or chemisorbed water molecules. If burners are used in the melting process, then hydroxyl ions can also be introduced through the combustion products from combustion of natural gas and related hydrocarbons, and thus it may be desirable to shift the energy used in melting from burners to electrodes to compensate. Alternatively, one might instead employ an iterative process of adjusting major oxide components so as to compensate for the deleterious impact of dissolved hydroxyl ions.

[00083] Sulfur is often present in natural gas, and likewise is a tramp component in many carbonate, nitrate, halide, and oxide raw materials. In the form of SO₂, sulfur can be a troublesome source of gaseous inclusions. The tendency to form SO₂-rich defects can be managed to a significant degree by controlling sulfur levels in the raw materials, and by incorporating low levels of comparatively reduced multivalent cations into the glass matrix. While not wishing to be bound by theory, it appears that SO₂-rich gaseous inclusions arise primarily through reduction of sulfate (SO₄⁼) dissolved in the glass. The elevated barium concentrations of exemplary glasses appear to increase sulfur retention in the glass in early stages of melting, but as noted above, barium is required to obtain low liquidus temperature, and hence high *T*_{35k-Tliq} and high liquidus viscosity. Deliberately controlling sulfur levels in raw materials to a low level is a useful means of reducing dissolved sulfur (presumably as sulfate) in the glass. In particular, sulfur is preferably less than 200ppm by weight in the batch materials, and more preferably less than 100ppm by weight in the batch materials.

[00084] Reduced multivalents can also be used to control the tendency of exemplary glasses to form SO₂ blisters. While not wishing to be bound to theory, these elements behave as potential electron donors that suppress the electromotive force for sulfate reduction. Sulfate reduction can be written in terms of a half reaction such as SO₄⁼ → SO₂ + O₂ + 2e⁻ where e⁻ denotes an electron. The “equilibrium constant” for the half reaction is $K_{eq} = \frac{[SO_2][O_2][e^-]^2}{[SO_4^{=}]}$ where the brackets denote chemical activities. Ideally one would like to force the reaction so as to create sulfate from SO₂, O₂ and 2e⁻. Adding nitrates, peroxides, or other oxygen-rich raw materials may help, but also may work against sulfate reduction in

the early stages of melting, which may counteract the benefits of adding them in the first place. SO₂ has very low solubility in most glasses, and so is impractical to add to the glass melting process. Electrons may be “added” through reduced multivalents. For example, an appropriate electron-donating half reaction for ferrous iron (Fe²⁺) is expressed as $2\text{Fe}^{2+} \rightarrow 2\text{Fe}^{3+} + 2\text{e}^-$

[00085] This “activity” of electrons can force the sulfate reduction reaction to the left, stabilizing SO₄⁼ in the glass. Suitable reduced multivalents include, but are not limited to, Fe²⁺, Mn²⁺, Sn²⁺, Sb³⁺, As³⁺, V³⁺, Ti³⁺, and others familiar to those skilled in the art. In each case, it may be important to minimize the concentrations of such components so as to avoid deleterious impact on color of the glass, or in the case of As and Sb, to avoid adding such components at a high enough level so as to complication of waste management in an end-user’s process.

[00086] In addition to the major oxides components of exemplary glasses, and the minor or tramp constituents noted above, halides may be present at various levels, either as contaminants introduced through the choice of raw materials, or as deliberate components used to eliminate gaseous inclusions in the glass. As a fining agent, halides may be incorporated at a level of about 0.4 mol% or less, though it is generally desirable to use lower amounts if possible to avoid corrosion of off-gas handling equipment. In some embodiments, the concentrations of individual halide elements are below about 200ppm by weight for each individual halide, or below about 800ppm by weight for the sum of all halide elements.

[00087] In addition to these major oxide components, minor and tramp components, multivalents and halide fining agents, it may be useful to incorporate low concentrations of other colorless oxide components to achieve desired physical, optical or viscoelastic properties. Such oxides include, but are not limited to, TiO₂, ZrO₂, HfO₂, Nb₂O₅, Ta₂O₅, MoO₃, WO₃, ZnO, In₂O₃, Ga₂O₃, Bi₂O₃, GeO₂, PbO, SeO₃, TeO₂, Y₂O₃, La₂O₃, Gd₂O₃, and others known to those skilled in the art. Through an iterative process of adjusting the relative proportions of the major oxide components of exemplary glasses, such colorless oxides can be added to a level of up to about 2 mol% without unacceptable impact to annealing point, *T*_{35k-Tliq} or liquidus viscosity.

[00088] Table 5 shows examples of glasses (samples 1-106) having a high transmissibility as described herein. These examples, however, should not limit the scope of the claims appended herewith as suitable glass compositions for exemplary composite articles and light guide plates are also described in Tables 6-12 below.

TABLE 5

	1	2	3	4	5	6	7
SiO ₂	73.14	68.94	76.51	77.73	68.72	74.43	72.53
Al ₂ O ₃	6.95	9.06	3.97	4.22	9.13	6.44	7.67
B ₂ O ₃	0	7.21	0	0	7.21	3.74	7.59
Li ₂ O	0	0	0	0	0	0	0
Na ₂ O	10.78	10.02	8.79	10.74	10.17	9.8	7.75
K ₂ O	0	0.6	0	0.02	0.63	0	0.01
ZnO	0	0	0.97	0.97	0	0.01	0.96
MgO	6.01	1.99	6.61	5.79	3.04	4.39	1.23
CaO	0.04	0.04	0.04	0.03	0.92	0.03	0.03
SrO	2.96	1.99	2.98	0.37	0	1.05	2.09
BaO	0	0	0	0	0	0	0
SnO ₂	0.07	0.1	0.09	0.09	0.09	0.08	0.07
R ₂ O/Al ₂ O ₃	1.55	1.17	2.21	2.55	1.18	1.52	1.01
(R ₂ O+RO)/Al ₂ O ₃	2.85	1.62	4.88	4.25	1.62	2.37	1.57
R ₂ O - Al ₂ O ₃ +MgO	-2.18	-0.43	-1.79	0.75	-1.37	-1.03	-1.14
strain	580	540	575	562	535	559	543
anneal	629	584	625	615	581	606	589
soft	871.4	806	868.9	867.6	823	841.5	830.2
CTE	68.5	66.5	61	64.5	66.6	62.4	55.2
density	2.477	2.425	2.469	2.401	2.382	2.401	2.402
strain (bbv)	574.7	532.2	572.1	560	531.6	551.4	537.7
anneal (bbv)	622.9	578	621	609.9	578.1	599.9	584.9
Color shift			0.005664			0.007524	
Viscosity							
A	-2.074	-1.614	-1.873	-1.89	-1.945	-1.65	-1.802
B	6417.4	5769.2	5987.3	6330	6446.7	6045.6	6467.9
To	205.2	188	228.4	193.9	152.3	194.5	153.6
T(200P)	1672	1662	1663	1704	1671	1725	1730
72hr gradient boat							
int	1005	935	1015	970	965	970	935
int liq visc	8.91E+05		5.48E+05	1.85E+06		1.40E+06	2.99E+06

	8	9	10	11	12	13	14
SiO ₂	74.49	70.26	72.16	68.99	69.58	77.04	72.25
Al ₂ O ₃	7.13	8.66	7.68	9.01	9.72	3.67	7.65
B ₂ O ₃	1.88	7.59	7.63	7.18	7.48	1.89	7.56
Li ₂ O	0	0	0	0	0	0	0
Na ₂ O	10.09	7.79	6.98	9.05	9.2	10.64	8.08
K ₂ O	0	1.16	1.04	0.59	0.42	0	0.01
ZnO	0	0	0	0	0	0	0.96
MgO	3.43	2.26	2.25	3.05	2.37	6.58	1.72
CaO	0.03	0.04	0.04	0.04	0.03	0.03	0.03
SrO	2.8	2.09	2.09	1.92	1.06	0	1.59
BaO	0	0	0	0	0	0	0
SnO ₂	0.08	0.07	0.07	0.09	0.07	0.08	0.08
R ₂ O/Al ₂ O ₃	1.42	1.03	1.04	1.07	0.99	2.90	1.06
(R ₂ O+RO)/Al ₂ O ₃	2.29	1.54	1.61	1.63	1.35	4.70	1.62
R ₂ O - Al ₂ O ₃ +MgO	-0.47	-1.97	-1.91	-2.42	-2.47	0.39	-1.28
strain	567	543	544	547	550	544	541

anneal	614	589	591	591	598	591	587
soft	857.2	832.3	840.8	828.8	872.5	830.3	838.8
CTE	64.9	61.3	56.8	63.3	60.9	64.2	55.1
density	2.452	2.402	2.388	2.414	2.375	2.385	2.389
strain (bbv)	560.5	536.5	539.6	538.5	542	538.6	535.7
anneal (bbv)	607.9	585	588.1	585.7	593.2	585.9	583.7
Color shift							
Viscosity							
A	-1.739	-1.9	-1.9	-1.946	-2.425	-1.683	-2.028
B	6089.3	6503.7	6594.4	6398.2	7698.3	5890.6	6953.1
To	202	152.4	149.6	162.6	97.6	192.6	126.4
T(200P)	1709	1701	1719	1669	1727	1671	1733
72hr gradient boat							
int	990	925	930	975	1010	990	900
int liq visc	9.74E+05	3.30E+06	3.55E+06		1.03E+06	5.06E+05	9.12E+06

	15	16	17	18	19	20	21
SiO2	70.31	73.35	75.15	76.88	75.67	76.97	77.64
Al2O3	8.68	3.97	3.98	4.18	5.79	4.68	3.96
B2O3	9.51	0	0	0	1.75	0	0
Li2O	0	0	0	0	0	0	0
Na2O	7.81	10.84	12.86	11.69	10.67	8.71	10.7
K2O	1.16	0	0	0	0	2.9	0
ZnO	0	0	0	0	0.01	0	0.98
MgO	1.24	6.73	6.79	7.08	5.44	6.59	6.08
CaO	0.03	0.04	0.03	0.03	0.03	0.03	0.03
SrO	1.11	4.89	1.02	0	0.53	0	0
BaO	0	0.03	0.01	0	0	0	0.49
SnO2	0.08	0.09	0.1	0.1	0.08	0.08	0.09
R2O/Al2O3	1.03	2.73	3.23	2.80	1.84	2.48	2.70
(R2O+RO)/Al2O3	1.31	5.68	5.20	4.50	2.88	3.90	4.62
R2O - Al2O3+MgO	-0.95	0.14	2.09	0.43	-0.56	0.34	0.66
strain	525	538	523	552	565	549	557
anneal	575	582	570	603	613	603	609
soft	828.4	797.6	813.2	853.3	860.1	870.4	862.3
CTE	59.7	73.5	74	69.1	64.7	73.2	65
density	2.353	2.506	2.424	2.386	2.398	2.385	2.414
strain (bbv)	519.4	531.7	518.2	549.9	557.8	546.5	555.6
anneal (bbv)	568.4	576.9	564.3	599	605.9	598.2	604.6
Color shift					0.006389		
Viscosity							
A	-1.9	-1.79	-1.911	-2.073	-1.873	-2.356	-1.959
B	6845.9	5350.3	5970.1	6603.1	6377.4	7386.5	6333.5
To	111.1	224.4	171.2	168.6	183.8	124.5	189.8
T(200P)	1741	1532	1589	1678	1712	1711	1677
72hr gradient boat							
int	830	890	855	940	950	840	950
int liq visc	4.20E+07	1.77E+06	6.60E+06	3.07E+06	2.82E+06	9.28E+07	2.36E+06

	22	23	24	25	26	27	28
SiO2	75.22	77.56	72.53	77.31	72.17	68.19	72.39
Al2O3	6.94	3.96	6.83	4.98	7.68	10.84	7.38
B2O3	0	0	9.75	0	7.63	7.37	7.45

Li2O	0	0	0	0	1.06	0	0
Na2O	12.77	10.26	6.78	11.19	6.98	10.47	8.52
K2O	0	0	0.01	0	0.01	0.01	0
ZnO	0	0.97	0	0.01	0	0	0
MgO	1.93	6.61	1.96	6.37	2.24	2.42	2.09
CaO	0.03	0.03	0.04	0.03	0.03	0.04	0.02
SrO	2.97	0	1.95	0	2.09	0.53	2.01
BaO	0	0.48	0	0	0	0	0
SnO2	0.07	0.09	0.09	0.08	0.08	0.07	0.08
R2O/Al2O3	1.84	2.59	0.99	2.25	1.05	0.97	1.15
(R2O+RO)/Al2O3	2.55	4.63	1.57	3.53	1.62	1.24	1.71
R2O - Al2O3+MgO	3.9	-0.31	-2	-0.16	-1.87	-2.78	-0.95
strain	534	567	535	573	529	553	546
anneal	581	619	583	626	576	604	591
soft	813.3	872.3	835.4	880.9	826.8	881.8	823
CTE	74.1	63.5	50.2	66.5	53.7	63.2	58.4
density	2.468	2.413	2.356	2.38	2.386	2.369	2.393
strain (bbv)	525.8	561	532.7	568.6	525.3	547.8	540.8
anneal (bbv)	572.9	612.8	681.5	619.4	571.5	600.2	587.3
Color shift				0.00606			
Viscosity							
A	-1.567	-1.933	-1.9	-1.997	-1.81	-2.843	-1.536
B	5710.6	6346.9	6842.9	6560.7	6533.2	8399.5	5834.9
To	189	197.7	129	190.9	134.7	75.5	192.8
T(200P)	1665	1697	1758	1717	1724	1708	1713
72hr gradient boat							
int	960	990	930	880	940	1000	910
int liq visc	6.91E+05	1.20E+06	4.39E+06	3.34E+07	2.01E+06	1.75E+06	3.98E+06

	29	30	31	32	33	34	35
SiO2	72.28	73.65	75.25	75.63	76.37	73.43	70.93
Al2O3	7.37	7.32	5.97	5.01	5.17	6.71	8.63
B2O3	7.34	3.84	0.96	1.72	0	5.61	7.58
Li2O	0	0	0	0	0	0	0
Na2O	8.96	9.39	10.77	10.55	11.17	6.52	8.08
K2O	0	0	0	0	0	0.97	0.76
ZnO	0	0	0	0	0	0	0
MgO	1.99	3.05	3.84	3.88	6.11	2.47	2.28
CaO	0.02	0.03	0.03	0.03	0.03	0.87	0.04
SrO	1.9	2.58	3.03	3.04	1.01	3.25	1.56
BaO	0	0	0	0	0	0.05	0
SnO2	0.08	0.08	0.08	0.07	0.09	0.08	0.07
R2O/Al2O3	1.22	1.28	1.80	2.11	2.16	1.12	1.02
(R2O+RO)/Al2O3	1.75	2.06	2.96	3.49	3.54	2.11	1.47
R2O - Al2O3+MgO	-0.4	-0.98	0.96	1.66	-0.11	-1.69	-2.07
strain	547	559	551	539	561	558	543
anneal	591	606	598	585	613	603	592
soft	816.4	843.7	832.6	806.9	865.0	835.9	852.7
CTE	57.1	61.7	67.8	67.1	68.2	57.8	59.2
density	2.397	2.437	2.463	2.464	2.411	2.442	2.382
strain (bbv)	539.9	552.7	545.8	532.8	560	551.9	537.8
anneal (bbv)	585.9	600.6	593.7	577.8	609.4	599	587.6
Color shift							
Viscosity							

A	-1.49	-1.753	-1.659	-1.563	-1.949	-1.721	-2.165
B	5653	6249.6	5855.6	5507.5	6428.1	6078.8	7218.9
To	202.9	183.5	202.4	206.6	190.5	191.9	115.6
T(200P)	1694	1725	1681	1632	1703	1703	1732
72hr gradient boat							
int	920	960	935	890	920	920	960
int liq visc	2.47E+06	1.97E+06	2.16E+06	3.13E+06	7.29E+06	4.24E+06	2.42E+06

	36	37	38	39	40	41	42
SiO ₂	77.84	74.12	68.66	74.36	68.62	72.25	72.23
Al ₂ O ₃	4.35	6.06	10.09	6.45	10.06	7.65	7.62
B ₂ O ₃	0	3.78	7.25	3.86	7.29	7.56	9.1
Li ₂ O	0	0	0	0	0	0	0
Na ₂ O	10.65	5	10.24	9.76	11.01	8.08	7.53
K ₂ O	0	1.93	0.65	0	0	0.01	0.01
ZnO	0.96	0	0	0	0	0.96	0
MgO	6.05	2.77	2.02	4.35	1.93	1.72	2.24
CaO	0.03	1.73	0.92	0.03	0.02	0.03	0.03
SrO	0	4.41	0	1.04	0.93	1.59	1.09
BaO	0	0.07	0	0.01	0	0	0
SnO ₂	0.09	0.08	0.1	0.07	0.08	0.08	0.08
R ₂ O/Al ₂ O ₃	2.45	1.14	1.08	1.51	1.09	1.06	0.99
(R ₂ O+RO)/Al ₂ O ₃	4.07	2.63	1.37	2.36	1.38	1.62	1.43
R ₂ O - Al ₂ O ₃ +MgO	0.25	-1.9	-1.22	-1.04	-0.98	-1.28	-2.32
strain	572	572	540	554	553	541	535
anneal	625	617	588	601	598	587	585
soft	880.6	851.4	842.9	840.9	847.6	838.8	859.3
CTE	64.1	59.7	66.4	62	65.7	55.1	52.3
density	2.392	2.485	2.373	2.405	2.387	2.389	2.340
strain (bbv)	570.1	565.6	536.1	545.1	543	535.7	533
anneal (bbv)	621	613.2	585.1	593.1	591	583.7	584.1
Color shift							
Viscosity							
A	-1.975	-1.855	-2.206	-1.828	-1.755	-2.028	-2.186
B	6471.2	6197.3	7123.4	6425.7	6217.7	6953.1	7447.2
To	198.1	202.4	120.6	165.8	176.7	126.4	97.3
T(200P)	1711	1694	1701	1722	1710	1733	1757
72hr gradient boat							
int	950	975	920	965	975	900	995
int liq visc	4.28E+06	1.47E+06		1.63E+06	1.08E+06	9.12E+06	1.29E+06

	43	44	45	46	47	48	49
SiO ₂	75.59	77.16	76.9	74.95	72.58	72.21	76.24
Al ₂ O ₃	4.99	3.95	4.68	5.43	6.98	7.57	5.16
B ₂ O ₃	1.84	0	0	1.78	7.49	8.61	0
Li ₂ O	0	0	0	0	0	0	0
Na ₂ O	5.75	10.84	11.68	3.52	8.51	7.05	9.83
K ₂ O	4.83	0	0	2.9	0	1.05	0
ZnO	0	0	0	0	0	0	0.01
MgO	3.84	4.86	6.57	3.08	2.19	2.25	6.6
CaO	0.03	0.03	0.03	2.6	0.02	0.03	0.03
SrO	2.99	3.01	0	5.54	2.07	1.09	2.01
BaO	0	0	0	0.09	0	0	0

SnO2	0.08	0.09	0.08	0.08	0.08	0.08	0.07
R2O/Al2O3	2.12	2.74	2.50	1.18	1.22	1.07	1.91
(R2O+RO)/Al2O3	3.49	4.74	3.91	3.27	1.83	1.52	3.58
R2O - Al2O3+MgO	1.75	2.03	0.43	-2.09	-0.66	-1.72	-1.93
strain	540	528	558	590	547	534	579
anneal	586	577	610	639	591	582	631
soft	818.4	814.9	867.7	878.7	814.5	846.6	884.8
CTE	73.4	69.3	68.6	61.2	57.3	56	63.2
density	2.463	2.437	2.385	2.52	2.397	2.351	2.43
strain (bbv)	532.3	524	554	585.9	540.2	529.1	577.5
anneal (bbv)	579.8	570.9	604.9	635.6	585.9	579.2	628.4
Color shift							0.006504
Viscosity							
A	-1.822	-1.824	-2.042	-2.01	-1.511	-1.929	-1.989
B	6267.2	6020.9	6562.4	6255.3	5752.6	6970.1	6434.3
To	163.4	172.3	177.1	227	196.1	116.2	208.5
T(200P)	1683	1632	1688	1678	1705	1764	1708
72hr gradient boat							
int	875	950	925	1030	880	990	1005
int liq visc	9.66E+06	8.28E+05	5.40E+06	6.02E+05	7.95E+06	1.12E+06	1.23E+06

	50	51	52	53	54	55	56
SiO2	72.07	78.17	76.91	68.92	68.69	69.67	68.29
Al2O3	7.6	3.98	5.18	11.68	10.07	9.7	10.78
B2O3	7.44	0	0.85	4.69	9.12	7.44	7.35
Li2O	0	0	0	0	0	0	0
Na2O	8.02	10.86	10.49	12.03	9.44	9.54	10.17
K2O	0.01	0	0	0.01	0.56	0.05	0.26
ZnO	0.49	0	0.01	0	0	0	0
MgO	2.16	6.82	6.43	2.49	1.02	2.36	2.44
CaO	0.03	0.03	0.03	0.04	0.93	0.04	0.04
SrO	2.03	0	0	0	0	1.06	0.53
BaO	0	0	0	0	0	0	0
SnO2	0.08	0.08	0.08	0.1	0.1	0.07	0.08
R2O/Al2O3	1.06	2.73	2.03	1.03	0.99	0.99	0.97
(R2O+RO)/Al2O3	1.68	4.45	3.27	1.25	1.19	1.35	1.25
R2O - Al2O3+MgO	-1.73	0.06	-1.12	-2.13	-1.09	-2.47	-2.79
strain	546	559	574	570	531	550	554
anneal	593	613	625	626	582	600	605
soft	835.8	872.1	878.8	913.3	859	878.8	881.1
CTE	55.500	65	63.3	68.6	62.5	60.4	63.5
density	2.396	2.375	2.38	2.382	2.343	2.376	2.369
strain (bbv)	541.1	556.1	573.2	567.8	52.4	543.8	547.1
anneal (bbv)	588.7	606.2	623.9	621.6	576.2	594.7	599.8
Color shift			0.007294				
Viscosity							
A	-1.876	-2.061	-1.911	-3.038	-2.708	-2.44	-2.986
B	6540.5	6732.8	6471.3	8948.7	8488.2	7713.5	8750.3
To	154.5	166.8	199.3	66.9	36.4	100.1	55.9
T(200P)	1720	1710	1736	1743	1731	1727	1711
72hr gradient boat							
int	950	980	1000	1050		1010	1020
int liq visc	2.22E+06	1.65E+06	1.48E+06			1.09E+06	1.23E+06

	57	58	59	60	61	62	63
SiO ₂	72.27	72.33	76.84	75.46	76.22	71.9	75.36
Al ₂ O ₃	7.66	7.7	4.69	5.78	4.95	8.56	6.98
B ₂ O ₃	7.61	7.6	0	1.88	0	1.93	0.85
Li ₂ O	0	0	0	0	0	0	0
Na ₂ O	7.95	8.12	11.68	10.75	9.84	12.43	12.28
K ₂ O	0	0	0	0	0	0	0
ZnO	0	0	0	0	0	0	0
MgO	0	1.41	6.61	5.42	5.83	5.01	4.35
CaO	0.02	1.21	0.03	0.03	0.03	0.03	0.02
SrO	4.35	1.47	0	0.53	2.98	0	0
BaO	0	0	0	0.01	0	0	0
SnO ₂	0.07	0.08	0.1	0.08	0.07	0.11	0.11
R ₂ O/Al ₂ O ₃	1.04	1.05	2.49	1.86	1.99	1.45	1.76
(R ₂ O+RO)/Al ₂ O ₃	1.61	1.59	3.91	2.90	3.77	2.04	2.39
R ₂ O - Al ₂ O ₃ +MgO	0.29	-0.99	0.38	-0.45	-0.94	-1.14	0.95
strain	557	554	558	556	559	575	567
anneal	601	599	610	605	610	624	619
soft	814.2	834.4	862.2	849.3	858.6	876.6	874
CTE	57.1	55.7	68.3	64.6	65.5	71.3	69.9
density	2.454	2.382	2.386	2.403	2.457	2.403	2.393
strain (bbv)	551	548.3	555.7	551.8	557.3	568.9	563.8
anneal (bbv)	596.6	595.9	605.5	599.9	606.6	619.3	614
Color shift							0.006152
Viscosity							
A	-1.096	-1.687	-1.965	-1.897	-2.051	-2.111	-1.692
B	4896.4	6247.9	6387.6	6438.4	6470.3	6794.6	6145
To	259.3	178.2	187.4	174.3	184.4	177.5	205
T(200P)	1701	1745	1685	1708	1671	1718	1744
72hr gradient boat							
int	920	930	915	935	955	1035	940
int liq visc	2.07E+06	4.20E+06	6.52E+06	3.69E+06	2.22E+06		

	64	65	66	67	68	69	70
SiO ₂	77.57	72.11	68.75	70.16	72.2	72.3	68.51
Al ₂ O ₃	4.15	7.71	10.1	8.97	7.66	7.19	10.74
B ₂ O ₃	0	7.64	7.36	7.22	7.61	7.53	6.43
Li ₂ O	0	2.06	0	0	0	0	0
Na ₂ O	10.5	6	9.41	10.47	8.05	8.05	10.77
K ₂ O	0	0.01	0.56	0.01	0.01	0.01	0
ZnO	0.97	0	0	0	0.97	0.95	0
MgO	6.65	2.24	1.01	1.99	2.23	1.72	2.33
CaO	0.03	0.03	0.64	0.03	0.03	0.03	0.02
SrO	0	2.1	2.01	1.01	1.1	2.08	1.06
BaO	0	0	0	0	0	0	0
SnO ₂	0.09	0.08	0.09	0.08	0.08	0.07	0.07
R ₂ O/Al ₂ O ₃	2.53	1.05	0.99	1.17	1.05	1.12	1.00
(R ₂ O+RO)/Al ₂ O ₃	4.37	1.61	1.35	1.51	1.62	1.79	1.32
R ₂ O - Al ₂ O ₃ +MgO	-0.3	-1.88	-1.14	-0.48	-1.83	-0.85	-2.3
strain	574	522	546	541	543	542	561
anneal	627	566	593	586	590	587	609
soft	878.3	804.2	834.7	822.3	846.3	823.3	866.2
CTE	63.6	51.7	64.4	63.6	54.8	55.1	65

density	2.393	2.384	2.415	2.389	2.376	2.407	2.393
strain (bbv)	573.5	515.1	539.5	533.9	535.6	535.6	554.1
anneal (bbv)	624.7	561.1	588	580.6	585.2	582.2	604.6
Color shift							
Viscosity							
A	-1.65	-1.745	-1.964	-1.733	-2.352	-1.688	-2.408
B	5771.2	6354.5	6613.2	6170.8	7658.8	6157.4	7567.5
To	242.7	133.1	150.8	165.5	90.3	169.2	119.5
T(200P)	1703	1704	1701	1695	1736	1713	1727
72hr gradient boat							
int	985	920	1010	930	1005	900	1030
int liq visc	1.33E+06			2.18E+06	1.05E+06	5.46E+06	8.01E+05

	71	72	73	74	75	76	77
SiO ₂	73.05	75.19	77.19	75.21	75.15	70.89	69.36
Al ₂ O ₃	7.5	3.98	3.97	4.96	6.95	8.6	9.74
B ₂ O ₃	5.62	0	0	0	0	7.41	7.05
Li ₂ O	0	0	0	0	0	0	0
Na ₂ O	8.72	12.83	9.87	10.83	10.84	9.4	10.88
K ₂ O	0	0	0	0	0	0	0
ZnO	0	0	0	0	0	0	0
MgO	2.61	6.78	6.8	5.84	3.87	2	1.91
CaO	0.02	0.03	0.03	0.03	0.03	0.02	0.9
SrO	2.34	1.02	1.99	2.97	2.98	1.52	0
BaO	0	0.02	0	0	0.04	0	0
SnO ₂	0.08	0.1	0.08	0.07	0.09	0.08	0.08
R ₂ O/Al ₂ O ₃	1.16	3.22	2.49	2.18	1.56	1.09	1.12
(R ₂ O+RO)/Al ₂ O ₃	1.83	5.20	4.71	3.97	2.56	1.50	1.41
R ₂ O - Al ₂ O ₃ +MgO	-1.39	2.07	-0.9	0.03	0.02	-1.2	-0.77
strain	554	523	554	547	572	550	547
anneal	600	570	606	596	623	596	594
soft	837.9	805.2	857.7	835.8	868.7	836.0	844.3
CTE	58	74.7	63.9	69	68.1	60.7	65.3
density	2.414	2.424	2.429	2.466	2.462	2.387	2.371
strain (bbv)	547.6	517.3	551.6	544.3	567.8	544.3	542.4
anneal (bbv)	594.2	565.1	600.3	591.4	617.5	591.9	590.1
Color shift							
Viscosity							
A	-1.767	-1.953	-2.106	-1.972	-1.83	-1.711	-1.969
B	6280.3	6035.8	6632.1	6181.9	6211.1	6180.4	6660.4
To	174.2	169.6	168.5	186.2	208.2	178.3	151.2
T(200P)	1718	1588	1673	1633	1712	1719	1711
72hr gradient boat							
int	970	855	1005	930	1000	940	950
int liq visc	1.33E+06	7.13E+06	6.64E+05	2.18E+06	1.03E+06	2.53E+06	2.34E+06

	78	79	80	81	82	83	84
SiO ₂	76.39	77.22	75.2	72.91	73.37	75.12	69.44
Al ₂ O ₃	5.17	6.93	6.95	7.8	7.06	6.97	9.75
B ₂ O ₃	0	0	0	2.58	5.63	0	6.48
Li ₂ O	0	0	0	0	0	0	0
Na ₂ O	11.65	10.78	8.87	11.5	8.94	12.81	10.79
K ₂ O	0	0	0	0	0	0	0

ZnO	0	0	0	0	0.01	0	0
MgO	6.11	1.95	3.88	5.03	3.3	3.93	2.31
CaO	0.03	0.03	0.03	0.03	0.03	0.03	0.02
SrO	0.51	2.96	4.92	0	1.56	1	1.06
BaO	0	0	0	0	0	0	0
SnO ₂	0.1	0.07	0.07	0.1	0.08	0.07	0.07
R ₂ O/Al ₂ O ₃	2.25	1.56	1.28	1.47	1.27	1.84	1.11
(R ₂ O+RO)/Al ₂ O ₃	3.54	2.27	2.55	2.12	1.96	2.55	1.45
R ₂ O - Al ₂ O ₃ +MgO	0.37	1.9	-1.96	-1.33	-1.42	1.91	-1.27
strain	556	560	590	562	556	555	555
anneal	608	611	641	611	602	603	600
soft	859.0	863.6	892.5	862.5	838	852.6	842.0
CTE	69.1	67.4	63.7	67.1	59	72.9	65.1
density	2.4	2.448	2.503	2.393	2.397	2.42	2.394
strain (bbv)	553.9	555.8	587.8	555.8	551.1	549	547.5
anneal (bbv)	602.6	605.6	637.8	605.8	597.7	598.3	595.7
Color shift					0.007476		
Viscosity							
A	-1.99	-1.703	-1.899	-2.078	-1.901	-1.844	-1.974
B	6544.9	6317.9	6249.2	6854.1	6483.7	6349.3	6617.5
To	173.3	184.1	227.5	157.9	168.1	178.9	160.3
T(200P)	1699	1762	1715	1723	1711	1711	1708
72hr gradient boat							
int	945	970	1030	1035	955	970	970
int liq visc	3.10E+06	2.17E+06	7.73E+05		2.18E+06	1.52E+06	1.58E+06

	85	86	87	88	89	90	91
SiO ₂	77.42	72.76	70.67	77.22	67.94	75.19	77.09
Al ₂ O ₃	3.94	5.01	8.25	3.96	10.68	6.93	3.98
B ₂ O ₃	0	8.32	8.43	0	7.19	0	0
Li ₂ O	0	0	0	0	0	0	0
Na ₂ O	9.86	4.14	7.12	10.91	10.88	10.81	10.88
K ₂ O	0	0.97	1.04	0	0.01	0	0
ZnO	0.97	0	0	0.97	0	0	0
MgO	6.64	4.31	2.22	6.77	2.32	1.95	6.85
CaO	0.03	0.05	0.04	0.03	0.04	0.03	0.03
SrO	1	4.27	2.08	0	0.81	4.96	1.03
BaO	0	0	0	0	0	0	0
SnO ₂	0.09	0.09	0.07	0.09	0.07	0.07	0.1
R ₂ O/Al ₂ O ₃	2.50	1.02	0.99	2.76	1.02	1.56	2.73
(R ₂ O+RO)/Al ₂ O ₃	4.70	2.74	1.52	4.72	1.32	2.56	4.72
R ₂ O - Al ₂ O ₃ +MgO	-0.72	-4.21	-2.31	0.18	-2.11	1.93	0.05
strain	573	560	540	566	547	555	549
anneal	624	604	586	618	596	603	599
soft	878.3	831.7	834.9	874	856.8	839	847.3
CTE	61.9	49.6	57.7	65.4	65.2	70.7	66.5
density	2.416	2.433	2.387	2.396	2.386	2.507	2.403
strain (bbv)	565.6	556.7	535.2	567.1	542	548.3	544.9
anneal (bbv)	616.3	605.8	583.8	617.3	591.2	596.8	593.9
Color shift	0.005265			0.004932			
Viscosity							
A	-2.029	-1.718	-1.884	-1.856	-2.605	-1.587	-1.976
B	6515.2	5894.9	6635.5	6077.3	7862.2	5648.3	6357.2
To	191.4	212.6	142.2	218.4	89.5	218.6	177.7

T(200P)	1696	1679	1728	1680	1692	1671	1664
72hr gradient boat							
int	1015	1000	935	960	975	990	950
int liq visc	7.61E+05		3.06E+06	2.18E+06	1.88E+06	5.43E+05	1.80E+06

	92	93	94	95	96	97	98
SiO2	69.17	72.45	77.4	74.55	72.35	73.14	72.43
Al2O3	8.97	7.6	4.14	6.83	7.63	7.05	7.63
B2O3	7.25	7.44	0	7.75	8.03	5.84	7.47
Li2O	0	0	0	0	0	0	0
Na2O	10.45	8.04	10.85	6.77	7.47	8.94	8.04
K2O	0.01	0	0	0.01	0.01	0	0
ZnO	0	0	0.97	0	0	0	0
MgO	2.95	0	5.99	1.95	2.23	3.29	0.04
CaO	0.04	0.02	0.03	0.04	0.03	0.03	4.24
SrO	1.01	0	0.5	1.95	2.09	1.57	0
BaO	0	4.3	0	0	0	0.02	0
SnO2	0.08	0.08	0.09	0.09	0.07	0.08	0.08
R2O/Al2O3	1.17	1.06	2.62	0.99	0.98	1.27	1.05
(R2O+RO)/Al2O3	1.61	1.63	4.43	1.57	1.55	1.96	1.61
R2O - Al2O3+MgO	-1.46	0.44	0.72	-2	-2.38	-1.4	0.37
strain	541	559	561	547	547	552	565
anneal	586	601	612	598	595	597	608
soft	825	801.3	870.6	861.6	854.2	838.1	834.5
CTE	63.9	58.8	65.3	49.8	53	58.2	56.5
density	2.396	2.530	2.407	2.361	2.378	2.402	2.372
strain (bbv)	535.1	552.1	557.4	544.8	541.6	543.1	559.6
anneal (bbv)	581.6	597	607.5	593.9	590.2	589.6	507.4
Color shift			0.004576				
Viscosity							
A	-1.784	-0.961	-1.889	-2.1	-2.075	-1.808	-1.29
B	6176.7	4553	6216.6	7434.6	7048	6390.8	5209.2
To	168.2	281.5	199.6	105.8	127.6	163	253.5
T(200P)	1680	1677	1683	1795	1738	1718	1704
72hr gradient boat							
int	940	875	950	945	970	985	980
int liq visc	1.66E+06	5.13E+06	2.49E+06	5.74E+06	1.96E+06	9.26E+05	7.59E+05

	99	100	101	102	103	104	105
SiO2	72.05	70.11	70.93	72.09	76.38	73.24	77.49
Al2O3	7.49	9.14	8.67	8.71	5.17	6.95	4.68
B2O3	7.41	7.31	7.52	7.69	0	0	0
Li2O	0	0	0	1.23	0	0	0
Na2O	7.93	10.11	8.79	7.86	11.16	12.77	10.76
K2O	0.01	0	0.01	0.01	0	0	0
ZnO	0.96	0	0	0	0	0	0.97
MgO	2.04	1.95	2.32	1.22	6.6	3.9	5.94
CaO	0.03	0.02	0.04	0.02	0.03	0.03	0.03
SrO	1.92	1.21	1.57	1.06	0.51	2.98	0
BaO	0	0	0	0	0	0	0
SnO2	0.08	0.07	0.08	0.08	0.1	0.07	0.09
R2O/Al2O3	1.06	1.11	1.01	1.04	2.16	1.84	2.30
(R2O+RO)/Al2O3	1.72	1.45	1.47	1.31	3.54	2.83	3.78

R2O - Al2O3+MgO	-1.59	-0.98	-2.19	-0.83	-0.61	1.92	0.14
strain	543	549	549	522	566	543	575
anneal	589	595	596	569	619	590	628
soft	835.2	833.1	859.5	831.8	873.9	824	886.8
CTE	54.3	62.6	58.2	55.8	67.5	75.7	64.8
density	2.401	2.386	2.382	2.357	2.399	2.48	2.394
strain (bbv)	538	590	542.5	523	564.2	539.7	572.5
anneal (bbv)	585.8	541.9	591.4	571.6	614.5	586.7	624.8
Color shift							0.005485
Viscosity							
A	-1.928	-1.78	-2.072	-1.893	-2.035	-1.734	-1.869
B	6686.9	6250.3	6986.5	6912	6543	5749.3	6229.9
To	143.2	173.7	133.5	112.3	187.6	205.4	216.6
T(200P)	1724	1705	1731	1760	1697	1630	1711
72hr gradient boat							
int	935	950	980	910	950	970	955
int liq visc	3.29E+06	1.87E+06	1.52E+06	5.91E+06	3.52E+06	6.10E+05	3.70E+06

	106
SiO2	77.67
Al2O3	4.34
B2O3	0
Li2O	0
Na2O	10.74
K2O	0
ZnO	0.97
MgO	5.88
CaO	0.03
SrO	0.25
BaO	0
SnO2	0.09
R2O/Al2O3	2.47
(R2O+RO)/Al2O3	4.12
R2O - Al2O3+MgO	0.52
strain	568
anneal	621
soft	876.7
CTE	64.9
density	2.398
strain (bbv)	564.8
anneal (bbv)	616.6
Color shift	
Viscosity	
A	-1.804
B	6165.5
To	210.5
T(200P)	1712
72hr gradient boat	
int	955
int liq visc	3.00E+06

[00089] Table 6 provides suitable alkali-containing and ion-exchangeable glasses for exemplary composite light guide plates and articles described herein.

TABLE 6

	mol%
SiO ₂	54-72
Al ₂ O ₃	8-17
B ₂ O ₃	0-8
P ₂ O ₅	0-7
R ₂ O	12-20
RO	0-8
B ₂ O ₃ + P ₂ O ₅	0-10
Al ₂ O ₃ + B ₂ O ₃ + P ₂ O ₅	8-25

[00090] Table 7 provides suitable display glasses for exemplary composite light guide plates and articles described herein.

TABLE 7

	mol%
SiO ₂	62-75
Al ₂ O ₃	8-15
B ₂ O ₃	0-12
RO	8-17
P ₂ O ₅	0-3

[00091] Table 8 provides suitable soda-lime glass compositions for exemplary composite light guide plates and articles described herein.

TABLE 8

	mol%
SiO ₂	63-81
Al ₂ O ₃	0-2
MgO	0-6
CaO	7-14
Li ₂ O	0-2
Na ₂ O	9-15
K ₂ O	0-1.5
Fe ₂ O ₃	0-0.6
Cr ₂ O ₃	0-0.2
MnO ₂	0-0.2
Co ₃ O ₄	0-0.1
TiO ₂	0-0.8
SO ₃	0-0.2
Se	0-0.1

[00092] Table 9 provides suitable borosilicate glass compositions for exemplary composite light guide plates and articles described herein.

TABLE 9

	mol%
SiO ₂	43-74
B ₂ O ₃	0-8.5
Al ₂ O ₃	6-10
MgO	0.5-9
CaO	15-28
Na ₂ O	0-2.5
K ₂ O	0-0.5
Fe ₂ O ₃	0-0.3
TiO ₂	0-1
F	0-2

[00093] Table 10 provides further suitable display glass compositions for exemplary composite light guide plates and articles described herein.

TABLE 10

	mol%
SiO ₂	62-85
Al ₂ O ₃	0.5-2.5
MgO	0-2.7
CaO	0-4.5
SrO	0.5-7.5
BaO	0.5-6.5
Li ₂ O	0-1.5
Na ₂ O	6-11
K ₂ O	4-7
Fe ₂ O ₃	0-0.2
TiO ₂	0-0.5
CeO ₂	0-0.3
ZrO ₂	0-2
PbO	0-1
ZnO	0-1.5
As ₂ O ₃	0-0.1
Sb ₂ O ₃	0-0.2
F	0-3

[00094] Table 11 provides further suitable borosilicate glass compositions for exemplary composite light guide plates and articles described herein.

TABLE 11

	mol%
SiO ₂	65-85
Al ₂ O ₃	1-5
B ₂ O ₃	8-15
CaO	0-2.5
Na ₂ O	3-9
K ₂ O	0-2
BaO	0-1

[00095] Table 12 provides additional suitable borosilicate glass compositions for exemplary composite light guide plates and articles described herein.

TABLE 12

	mol%
SiO ₂	50-78
B ₂ O ₃	2.5-9
Al ₂ O ₃	0-4
MgO	1.5-8
CaO	5-15
Na ₂ O	12-18
K ₂ O	0-1.5
Fe ₂ O ₃	0-0.3
F	0-2.5
SO ₃	0-0.2

[00096] As noted in the above tables and discussion an exemplary article can comprise a composite sheet with a front face having a width and a height, a back face opposite the front face, and a thickness between the front face and back face, forming a first edge, second edge, third edge and fourth edge around the front and back faces, wherein the composite sheet comprises both glass and plastic materials. In some embodiments, the plastic material is selected from the group consisting of polymethylmethacrylate (PMMA), polycarbonate (PC), polyethylene terephthalate (PET), polymethylmethacrylate, polyether ether ketone, polyethylene naphthalate, poly(ethylene succinate), polypropylene, styrene-methacrylate copolymer (MS), and cyclic olefin copolymer (COC). In some embodiments, the glass material comprises between about 65.79 mol % to about 78.17 mol% SiO₂, between about 2.94 mol% to about 12.12 mol% Al₂O₃, between about 0 mol% to about 11.16 mol% B₂O₃, between about 0 mol% to about 2.06 mol% Li₂O, between about 3.52 mol% to about 13.25

mol% Na₂O, between about 0 mol% to about 4.83 mol% K₂O, between about 0 mol% to about 3.01 mol% ZnO, between about 0 mol% to about 8.72 mol% MgO, between about 0 mol% to about 4.24 mol% CaO, between about 0 mol% to about 6.17 mol% SrO, between about 0 mol% to about 4.3 mol% BaO, and between about 0.07 mol% to about 0.11 mol% SnO₂. In some embodiments, the glass material comprises between about 66 mol % to about 78 mol% SiO₂, between about 4 mol% to about 11 mol% Al₂O₃, between about 4 mol% to about 11 mol% B₂O₃, between about 0 mol% to about 2 mol% Li₂O, between about 4 mol% to about 12 mol% Na₂O, between about 0 mol% to about 2 mol% K₂O, between about 0 mol% to about 2 mol% ZnO, between about 0 mol% to about 5 mol% MgO, between about 0 mol% to about 2 mol% CaO, between about 0 mol% to about 5 mol% SrO, between about 0 mol% to about 2 mol% BaO, and between about 0 mol% to about 2 mol% SnO₂. In some embodiments, the glass material comprises between about 72 mol % to about 80 mol% SiO₂, between about 3 mol% to about 7 mol% Al₂O₃, between about 0 mol% to about 2 mol% B₂O₃, between about 0 mol% to about 2 mol% Li₂O, between about 6 mol% to about 15 mol% Na₂O, between about 0 mol% to about 2 mol% K₂O, between about 0 mol% to about 2 mol% ZnO, between about 2 mol% to about 10 mol% MgO, between about 0 mol% to about 2 mol% CaO, between about 0 mol% to about 2 mol% SrO, between about 0 mol% to about 2 mol% BaO, and between about 0 mol% to about 2 mol% SnO₂. In some embodiments, the glass material comprises between about 60 mol % to about 80 mol% SiO₂, between about 0 mol% to about 15 mol% Al₂O₃, between about 0 mol% to about 15 mol% B₂O₃, and about 2 mol% to about 50 mol% R_xO, wherein R is any one or more of Li, Na, K, Rb, Cs and x is 2, or Zn, Mg, Ca, Sr or Ba and x is 1, and wherein Fe + 30Cr + 35Ni < about 60 ppm. In some embodiments, the glass material has a CTE between about 49.6 x 10⁻⁷/ °C to about 70 x 10⁻⁷/ °C. In some embodiments, the glass material has a density between about 2.34 gm/cc @ 20 C and about 2.53 gm/cc @ 20 C. In some embodiments, the article is a light guide plate. In some embodiments, a display device comprises such a light guide plate. In some embodiments, the thickness of the plate is between about 0.2 mm and about 8 mm. In some embodiments, the thickness has a variation of less than 5%. In some embodiments, the glass material of the light guide plate is manufactured from a fusion draw process, slot draw process, or a float process. In some embodiments, the glass comprises less than 1 ppm each of Co, Ni, and Cr. In some embodiments, the concentration of Fe in the glass material is < about 50 ppm, < about 20 ppm, or < about 10 ppm. In some embodiments, Fe + 30Cr + 35Ni < about 60 ppm in the glass material, < about 40 ppm in the glass material, < about 20 ppm in the glass material, or < about 10 ppm in the glass material. In some embodiments, the

transmittance of the glass material at 450 nm with at least 500 mm in length is greater than or equal to 85%, the transmittance of the glass material at 550 nm with at least 500 mm in length is greater than or equal to 90%, or the transmittance of the glass material at 630 nm with at least 500 mm in length is greater than or equal to 85%, and combinations thereof. In some embodiments, the transmittance of the glass material is substantially similar to the transmittance of the plastic material. In some embodiments, the glass material has a color shift < 0.015 or < 0.008 . In some embodiments, the glass material has a color shift substantially similar to the color shift of the plastic material. In some embodiments, the glass material is positioned along the first edge, the second edge, the third edge, the fourth edge, or combinations thereof. In some embodiments, the glass material is positioned at a distance from $0.5 \times$ width of the article to the first edge, $0.4 \times$ width of the article to the first edge, $0.3 \times$ width of the article to the first edge, $0.2 \times$ width of the article to the first edge, $0.1 \times$ width of the article to the first edge, $0.05 \times$ width of the article to the first edge, or $0.01 \times$ width of the article to the first edge. In some embodiments, the glass material is positioned at a distance from $0.5 \times$ height of the article to the second edge, $0.4 \times$ height of the article to the second edge, $0.3 \times$ height of the article to the second edge, $0.2 \times$ height of the article to the second edge, $0.1 \times$ height of the article to the second edge, $0.05 \times$ height of the article to the second edge, or $0.01 \times$ height of the article to the second edge.

[00097] It will be appreciated that the various disclosed embodiments may involve particular features, elements or steps that are described in connection with that particular embodiment. It will also be appreciated that a particular feature, element or step, although described in relation to one particular embodiment, may be interchanged or combined with alternate embodiments in various non-illustrated combinations or permutations.

[00098] It is also to be understood that, as used herein the terms “the,” “a,” or “an,” mean “at least one,” and should not be limited to “only one” unless explicitly indicated to the contrary. Thus, for example, reference to “a ring” includes examples having two or more such rings unless the context clearly indicates otherwise. Likewise, a “plurality” or an “array” is intended to denote “more than one.” As such, a “plurality of droplets” includes two or more such droplets, such as three or more such droplets, etc., and an “array of rings” comprises two or more such droplets, such as three or more such rings, etc.

[00099] Ranges can be expressed herein as from “about” one particular value, and/or to “about” another particular value. When such a range is expressed, examples include from the one particular value and/or to the other particular value. Similarly, when values are expressed as approximations, by use of the antecedent “about,” it will be understood that the

particular value forms another aspect. It will be further understood that the endpoints of each of the ranges are significant both in relation to the other endpoint, and independently of the other endpoint.

[000100] The terms “substantial,” “substantially,” and variations thereof as used herein are intended to note that a described feature is equal or approximately equal to a value or description. For example, a “substantially planar” surface is intended to denote a surface that is planar or approximately planar. Moreover, as defined above, “substantially similar” is intended to denote that two values are equal or approximately equal. In some embodiments, “substantially similar” may denote values within about 10% of each other, such as within about 5% of each other, or within about 2% of each other.

[000101] Unless otherwise expressly stated, it is in no way intended that any method set forth herein be construed as requiring that its steps be performed in a specific order. Accordingly, where a method claim does not actually recite an order to be followed by its steps or it is not otherwise specifically stated in the claims or descriptions that the steps are to be limited to a specific order, it is no way intended that any particular order be inferred.

[000102] While various features, elements or steps of particular embodiments may be disclosed using the transitional phrase “comprising,” it is to be understood that alternative embodiments, including those that may be described using the transitional phrases “consisting” or “consisting essentially of,” are implied. Thus, for example, implied alternative embodiments to a device that comprises A+B+C include embodiments where a device consists of A+B+C and embodiments where a device consists essentially of A+B+C.

[000103] It will be apparent to those skilled in the art that various modifications and variations can be made to the present disclosure without departing from the spirit and scope of the disclosure. Since modifications combinations, sub-combinations and variations of the disclosed embodiments incorporating the spirit and substance of the disclosure may occur to persons skilled in the art, the disclosure should be construed to include everything within the scope of the appended claims and their equivalents.

What is claimed is:

1. An article, comprising:
a composite sheet with a front face having a width and a height, a back face opposite the front face, and a thickness between the front face and back face, forming a first edge, second edge, third edge and fourth edge around the front and back faces,
wherein the composite sheet comprises both glass and plastic materials in a coplanar relationship.
2. An article, comprising:
a glass sheet with a front face having a width and a height, a back face opposite the front face, and a thickness between the front face and back face, forming a first edge, second edge, third edge and fourth edge around the front and back faces; and
a plastic sheet with a front face having a width and a height, a back face opposite the front face, and a thickness between the front face and back face, forming a first edge, second edge, third edge and fourth edge around the front and back faces,
wherein the front faces of the glass and plastic sheets are coplanar with each other,
and
wherein the back faces of the glass and plastic sheets are coplanar with each other.
3. The article of Claims 1 or 2, wherein the plastic material is selected from the group consisting of polymethylmethacrylate (PMMA), polycarbonate (PC), polyethylene terephthalate (PET), polymethylmethacrylate, polyether ether ketone, polyethylene naphthalate, poly(ethylene succinate), polypropylene, styrene-methacrylate copolymer (MS), and cyclic olefin copolymer (COC).
4. The article of Claims 1 or 2, wherein the glass material comprises:
between about 65.79 mol % to about 78.17 mol% SiO_2 ,
between about 2.94 mol% to about 12.12 mol% Al_2O_3 ,
between about 0 mol% to about 11.16 mol% B_2O_3 ,
between about 0 mol% to about 2.06 mol% Li_2O ,
between about 3.52 mol% to about 13.25 mol% Na_2O ,
between about 0 mol% to about 4.83 mol% K_2O ,
between about 0 mol% to about 3.01 mol% ZnO ,

between about 0 mol% to about 8.72 mol% MgO,
between about 0 mol% to about 4.24 mol% CaO,
between about 0 mol% to about 6.17 mol% SrO,
between about 0 mol% to about 4.3 mol% BaO, and
between about 0.07 mol% to about 0.11 mol% SnO₂.

5. The article of Claims 1 or 2, wherein the glass material comprises:

between about 66 mol % to about 78 mol% SiO₂,
between about 4 mol% to about 11 mol% Al₂O₃,
between about 4 mol% to about 11 mol% B₂O₃,
between about 0 mol% to about 2 mol% Li₂O,
between about 4 mol% to about 12 mol% Na₂O,
between about 0 mol% to about 2 mol% K₂O,
between about 0 mol% to about 2 mol% ZnO,
between about 0 mol% to about 5 mol% MgO,
between about 0 mol% to about 2 mol% CaO,
between about 0 mol% to about 5 mol% SrO,
between about 0 mol% to about 2 mol% BaO, and
between about 0 mol% to about 2 mol% SnO₂.

6. The article of Claims 1 or 2, wherein the glass material comprises:

between about 72 mol % to about 80 mol% SiO₂,
between about 3 mol% to about 7 mol% Al₂O₃,
between about 0 mol% to about 2 mol% B₂O₃,
between about 0 mol% to about 2 mol% Li₂O,
between about 6 mol% to about 15 mol% Na₂O,
between about 0 mol% to about 2 mol% K₂O,
between about 0 mol% to about 2 mol% ZnO,
between about 2 mol% to about 10 mol% MgO,
between about 0 mol% to about 2 mol% CaO,
between about 0 mol% to about 2 mol% SrO,
between about 0 mol% to about 2 mol% BaO, and
between about 0 mol% to about 2 mol% SnO₂.

7. The article of Claims 1 or 2, wherein the glass material comprises:
between about 60 mol % to about 80 mol% SiO_2 ,
between about 0 mol% to about 15 mol% Al_2O_3 ,
between about 0 mol% to about 15 mol% B_2O_3 , and
about 2 mol% to about 50 mol% R_xO ,
wherein R is any one or more of Li, Na, K, Rb, Cs and x is 2, or Zn, Mg, Ca, Sr or Ba
and x is 1, and
wherein $\text{Fe} + 30\text{Cr} + 35\text{Ni} < \text{about } 60 \text{ ppm}$.
8. The article of Claims 1 or 2, wherein the glass material comprises:
between about 54 mol % to about 72 mol% SiO_2 ,
between about 8 mol% to about 17 mol% Al_2O_3 ,
between about 0 mol% to about 8 mol% B_2O_3 ,
between about 0 mol% to about 7 mol% P_2O_5 ,
between about 12 mol% to about 20 mol% R_2O , R is any one or more of Li, Na, K,
Rb, Cs,
between about 0 mol% to about 8 mol% RO . R is any one or more of Zn, Mg, Ca, Sr
or Ba,
between about 0 mol% to about 10 mol% $\text{B}_2\text{O}_3 + \text{P}_2\text{O}_5$, and
between about 8 mol% to about 25 mol% $\text{Al}_2\text{O}_3 + \text{B}_2\text{O}_3 + \text{P}_2\text{O}_5$.
9. The article of Claims 1 or 2, wherein the glass material comprises:
between about 62 mol % to about 75 mol% SiO_2 ,
between about 8 mol% to about 15 mol% Al_2O_3 ,
between about 0 mol% to about 12 mol% B_2O_3 ,
between about 0 mol% to about 3 mol% P_2O_5 , and
between about 8 mol% to about 17 mol% RO . R is any one or more of Zn, Mg, Ca, Sr
or Ba.
10. The article of Claims 1 or 2, wherein the glass material comprises:
between about 63 mol % to about 81 mol% SiO_2 ,
between about 0 mol% to about 2 mol% Al_2O_3 ,
between about 0 mol% to about 2 mol% Li_2O ,
between about 9 mol% to about 15 mol% Na_2O ,

between about 0 mol% to about 1.5 mol% K_2O ,
between about 0 mol% to about 6 mol% MgO ,
between about 7 mol% to about 14 mol% CaO ,
between about 0 mol% to about 0.6 mol% Fe_2O_3 ,
between about 0 mol% to about 0.2 mol% Cr_2O_3 ,
between about 0 mol% to about 0.2 mol% MnO_2 ,
between about 0 mol% to about 0.1 mol% Co_3O_4 ,
between about 0 mol% to about 0.8 mol% TiO_2 ,
between about 0 mol% to about 0.2 mol% SO_3 , and
between about 0 mol% to about 0.1 mol% Se .

11. The article of Claims 1 or 2, wherein the glass material comprises:

between about 43 mol % to about 74 mol% SiO_2 ,
between about 0 mol% to about 8.5 mol% B_2O_3 ,
between about 6 mol% to about 10 mol% Al_2O_3 ,
between about 0 mol% to about 2.5 mol% Na_2O ,
between about 0 mol% to about 0.5 mol% K_2O ,
between about 0.5 mol% to about 9 mol% MgO ,
between about 15 mol% to about 28 mol% CaO ,
between about 0 mol% to about 0.3 mol% Fe_2O_3 ,
between about 0 mol% to about 1 mol% TiO_2 , and
between about 0 mol% to about 2 mol% F .

12. The article of Claims 1 or 2, wherein the glass material comprises:

between about 62 mol % to about 85 mol% SiO_2 ,
between about 0.5 mol% to about 2.5 mol% Al_2O_3 ,
between about 0 mol% to about 1.5 mol% Li_2O ,
between about 6 mol% to about 11 mol% Na_2O ,
between about 4 mol% to about 7 mol% K_2O ,
between about 0 mol% to about 2.7 mol% MgO ,
between about 0 mol% to about 4.5 mol% CaO ,
between about 0.5 mol% to about 7.5 mol% SrO ,
between about 0.5 mol% to about 6.5 mol% BaO ,
between about 0 mol% to about 0.2 mol% Fe_2O_3 ,

between about 0 mol% to about 2 mol% ZrO_2 ,
between about 0 mol% to about 1 mol% PbO ,
between about 0 mol% to about 0.3 mol% CeO_2 ,
between about 0 mol% to about 0.5 mol% TiO_2 ,
between about 0 mol% to about 1.5 mol% ZnO ,
between about 0 mol% to about 0.1 mol% As_2O_3 ,
between about 0 mol% to about 0.2 mol% Sb_2O_3 , and
between about 0 mol% to about 3 mol% F.

13. The article of Claims 1 or 2, wherein the glass material comprises:

between about 65 mol % to about 85 mol% SiO_2 ,
between about 1 mol% to about 5 mol% Al_2O_3 ,
between about 8 mol% to about 15 mol% B_2O_3 ,
between about 3 mol% to about 9 mol% Na_2O ,
between about 0 mol% to about 2 mol% K_2O ,
between about 0 mol% to about 2.5 mol% CaO , and
between about 0 mol% to about 1 mol% BaO ,

14. The article of Claims 1 or 2, wherein the glass material comprises:

between about 50 mol % to about 78 mol% SiO_2 ,
between about 0 mol% to about 4 mol% Al_2O_3 ,
between about 2.5 mol% to about 9 mol% B_2O_3 ,
between about 12 mol% to about 18 mol% Na_2O ,
between about 0 mol% to about 1.5 mol% K_2O ,
between about 1.5 mol% to about 8 mol% MgO ,
between about 5 mol% to about 15 mol% CaO ,
between about 0 mol% to about 0.3 mol% Fe_2O_3 ,
between about 0 mol% to about 0.2 mol% SO_3 , and
between about 0 mol% to about 2.5 mol% F.

15. The article of Claims 1 or 2, wherein the glass material has a CTE between about $30 \times 10^{-7}/^\circ\text{C}$ to about $120 \times 10^{-7}/^\circ\text{C}$.

16. The article of any of the preceding claims, wherein the article is a light guide plate.

17. A display device comprising the light guide plate of Claim 16.
18. The article of Claim 16, wherein the thickness of the plate is between about 0.2 mm and about 8 mm.
19. The article of Claim 16, wherein the thickness has a variation of less than 5%.
20. The article of Claim 16, wherein the glass material of the light guide plate is manufactured from a fusion draw process, slot draw process, or a float process.
21. The article of Claims 1 or 2, wherein the glass comprises less than 1 ppm each of Co, Ni, and Cr.
22. The article of Claims 1 or 2, wherein the concentration of Fe in the glass material is < about 50 ppm.
23. The article of Claims 1 or 2, wherein the transmittance of the glass material at 450 nm with at least 500 mm in length is greater than or equal to 85%, the transmittance of the glass material at 550 nm with at least 500 mm in length is greater than or equal to 90%, or the transmittance of the glass material at 630 nm with at least 500 mm in length is greater than or equal to 85%, and combinations thereof.
24. The article of Claims 1 or 2, wherein the transmittance of the glass material is substantially similar to the transmittance of the plastic material.
25. The article of Claims 1 or 2, wherein the glass material has a color shift < 0.008.
26. The article of Claims 1 or 2, wherein the glass material has a color shift substantially similar to the color shift of the plastic material.
27. The article of Claim 1, wherein the glass material is positioned along the first edge, the second edge, the third edge, the fourth edge, or combinations thereof.

28. The article of Claim 2, wherein the glass material is positioned along the first, second, third, fourth edges, or combinations thereof of the plastic material.

29. The article of Claim 1, wherein the glass material is positioned at a distance from 0.5*width of the article to the first edge, 0.4*width of the article to the first edge, 0.3*width of the article to the first edge, 0.2*width of the article to the first edge, 0.1*width of the article to the first edge, 0.05*width of the article to the first edge, or 0.01*width of the article to the first edge.

30. The article of Claim 1, wherein the glass material is positioned at a distance from 0.5*height of the article to the second edge, 0.4* height of the article to the second edge, 0.3* height of the article to the second edge, 0.2* height of the article to the second edge, 0.1* height of the article to the second edge, 0.05* height of the article to the second edge, or 0.01* height of the article to the second edge.

31. The article of Claims 1 or 2, wherein the glass material has a width W_G and wherein $1 \text{ cm} \leq W_G \leq 10 \text{ cm}$.

32. The article of Claims 1 or 2, wherein the glass material has a width W_G and wherein $2 \text{ cm} \leq W_G$.

33. The article of Claims 1 or 2, wherein the glass material has a width W_G and wherein $1 \text{ cm} \leq W_G \leq 50 \text{ cm}$.

34. The article of Claims 1 or 2, wherein the glass material has an absorbance $\Omega(\text{glass})$ wherein $\Omega(\text{glass}) \leq 0.7 \text{ dB/cm}$ at 450 nm and $\Omega(\text{glass}) \leq 0.5 \text{ dB/cm}$ at 550 nm, or $\Omega(\text{glass}) \leq 0.7 \text{ dB/cm}$ at 630 nm.

35. The article of Claims 1 or 2, wherein the glass material has an absorbance $\Omega(\text{glass})$ wherein $\Omega(\text{glass}) \leq 0.35 \text{ dB/cm}$ at 450 nm and $\Omega(\text{glass}) \leq 0.25 \text{ dB/cm}$ at 550 nm, or $\Omega(\text{glass}) \leq 0.35 \text{ dB/cm}$ at 630 nm.

36. The article of Claims 1 or 2, wherein the glass material has an absorbance $\Omega(\text{glass})$ wherein $\Omega(\text{glass}) \leq 0.14$ dB/cm at 450 nm and $\Omega(\text{glass}) \leq 0.10$ dB/cm at 550 nm, or $\Omega(\text{glass}) \leq 0.14$ dB/cm at 630 nm.

37. The article of Claims 1 or 2, wherein the glass material has an absorbance $\Omega(\text{glass})$ wherein $\Omega(\text{glass}) \leq 0.07$ dB/cm at 450 nm and $\Omega(\text{glass}) \leq 0.05$ dB/cm at 550 nm, or $\Omega(\text{glass}) \leq 0.07$ dB/cm at 630 nm.

38. The article of Claims 1 or 2, wherein the glass material has an absorbance $\Omega(\text{glass})$ wherein $\Omega(\text{glass}) \leq 0.014$ dB/cm at 450 nm and $\Omega(\text{glass}) \leq 0.010$ dB/cm at 550 nm, or $\Omega(\text{glass}) \leq 0.014$ dB/cm at 630 nm.

39. The article of Claims 1 or 2, wherein the glass material has an absorbance $\Omega(\text{glass})$ wherein $\Omega(\text{glass}) \leq 0.7$ dB/cm at 450 nm and $\Omega(\text{glass}) \leq 0.5$ dB/cm at 550 nm, or $\Omega(\text{glass}) \leq 0.7$ dB/cm at 630 nm.

40. The article of Claims 1 or 2, wherein the glass material has a width W_G and wherein $1 \text{ cm} \leq W_G \leq 10 \text{ cm}$ and wherein the glass material has an absorbance $\Omega(\text{glass})$ wherein $0.007 \text{ dB/cm} \leq \Omega(\text{glass}) \leq 0.7 \text{ dB/cm}$ for all wavelengths greater than or equal to 450 nm to less than or equal to 630 nm.

41. The article of Claims 1 or 2, wherein the glass material has a width W_G and wherein $1 \text{ cm} \leq W_G \leq 10 \text{ cm}$ and wherein the glass material has an absorbance $\Omega(\text{glass})$ wherein $0.35 \text{ dB/cm} \leq \Omega(\text{glass}) \leq 0.7 \text{ dB/cm}$ for all wavelengths greater than or equal to 450 nm to less than or equal to 630 nm.

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FIG. 1A

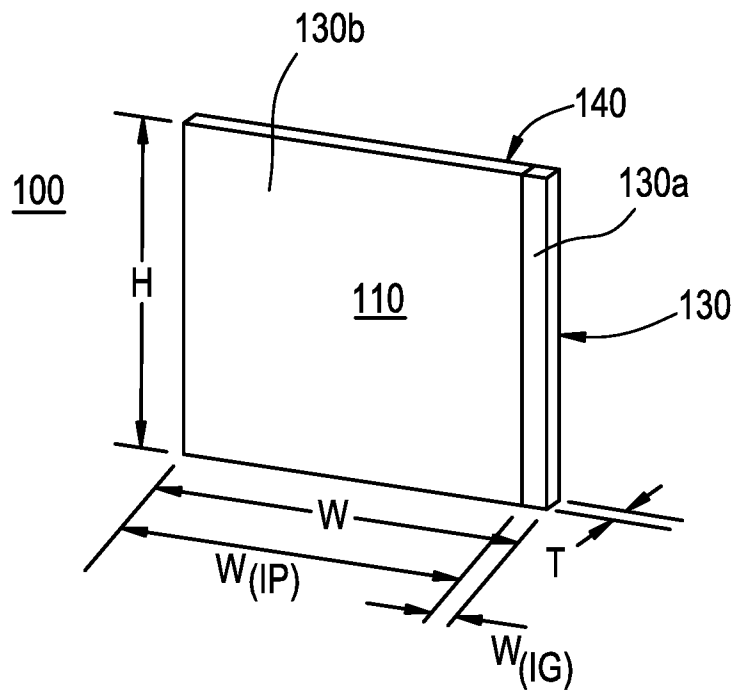
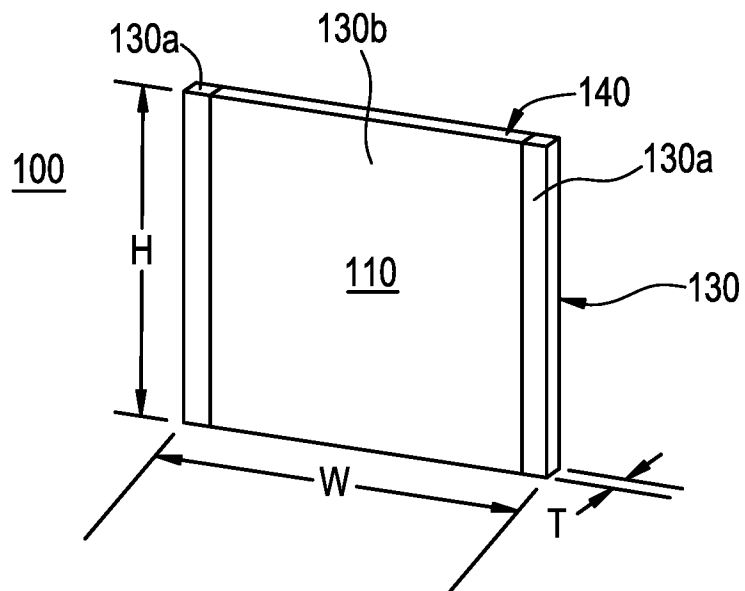


FIG. 1B



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FIG. 1C

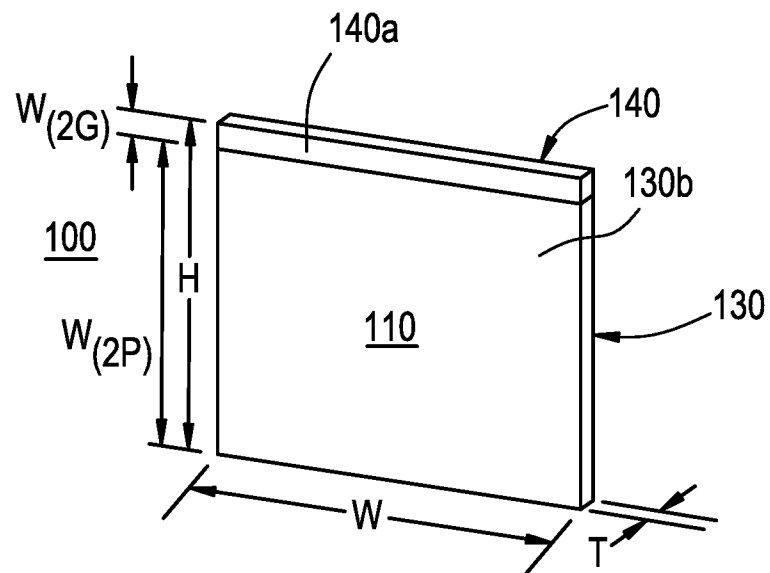
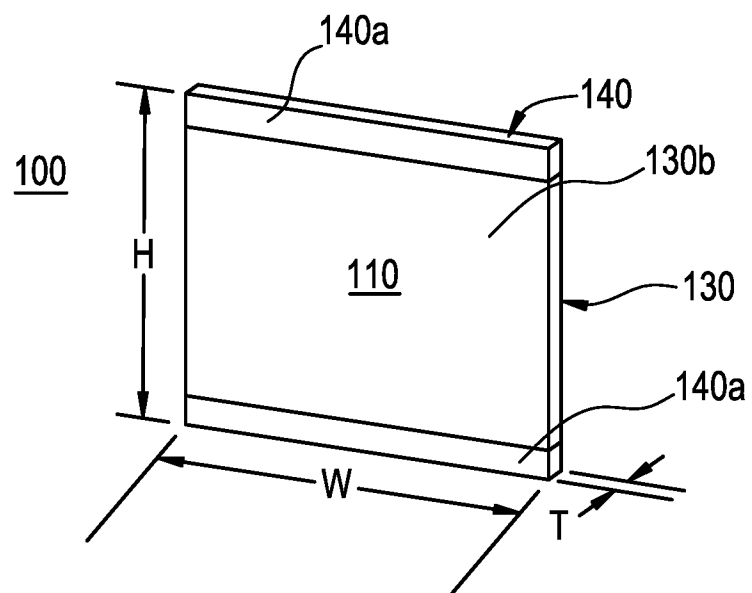


FIG. 1D



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FIG. 1E

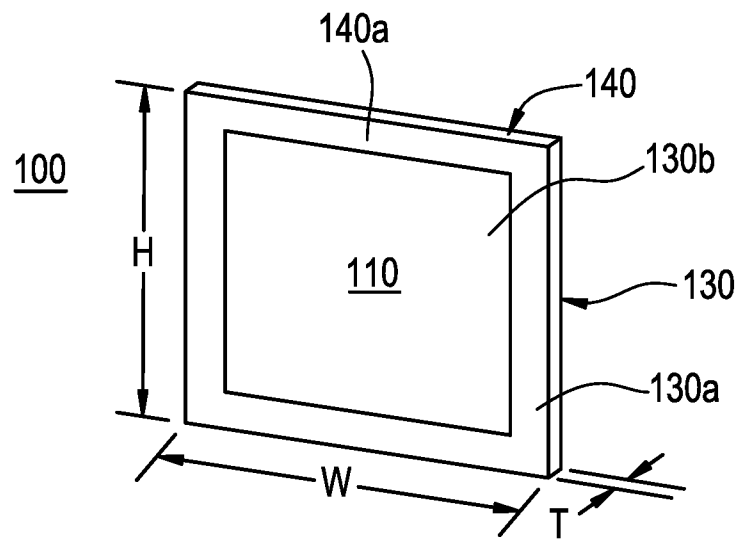
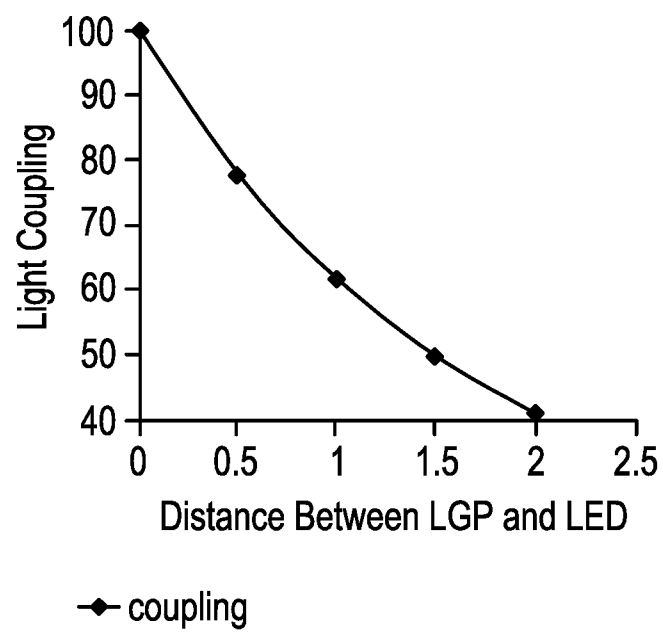


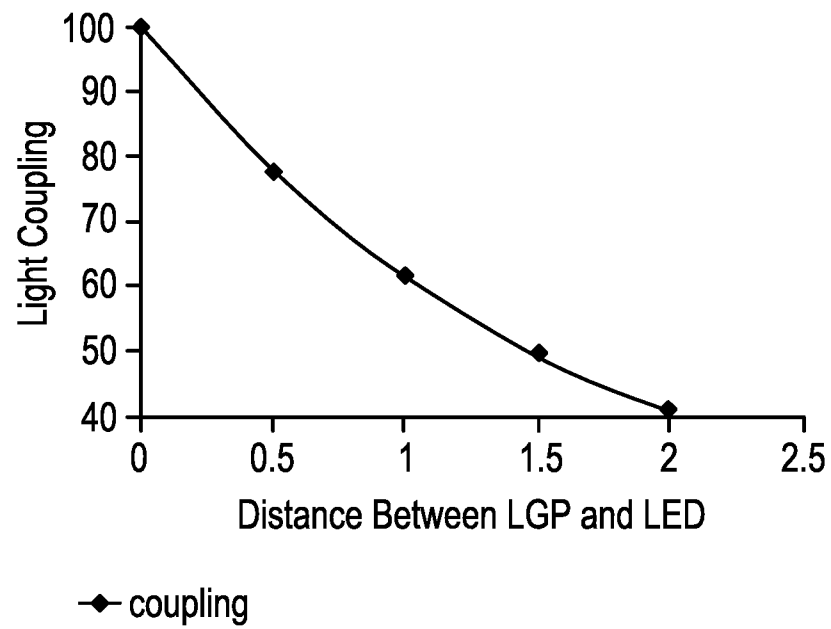
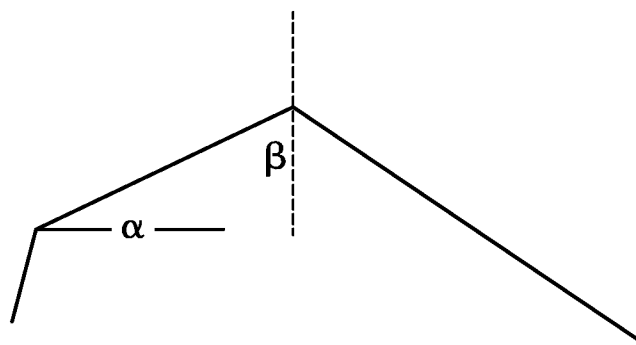
FIG. 2



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FIG. 3

Light coupling versus LED to LGP
distance

**FIG. 4**

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FIG. 5

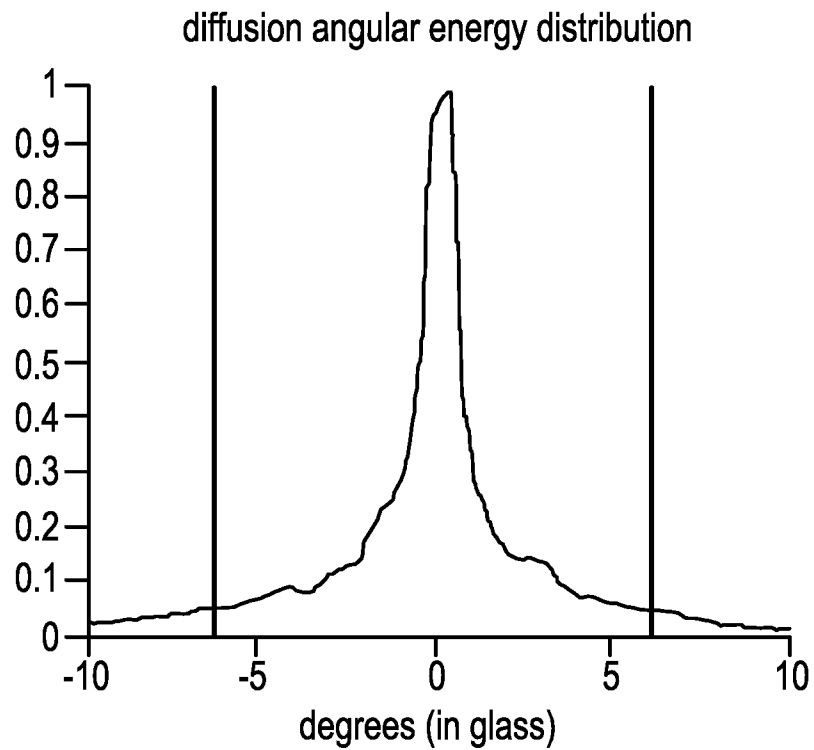
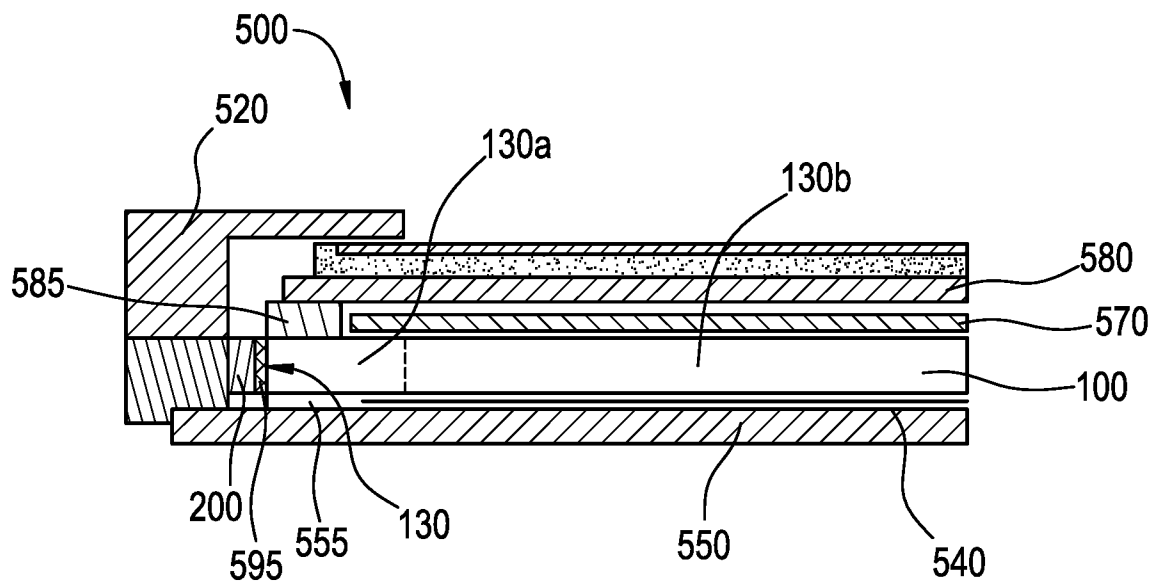


FIG. 6



INTERNATIONAL SEARCH REPORTInternational application No.
PCT/US2017/017338**Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)**

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☒ Claims Nos.: 17-20
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
Claims 17-20 are regarded to be unclear because the claims refer to multiple dependent claims which do not comply with PCT Rule 6.4(a).
3. ☒ Claims Nos.: 16
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of any additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/017338**A. CLASSIFICATION OF SUBJECT MATTER****F21V 8/00(2006.01)i**

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F21V 8/00; G03G 5/10; G01T 5/00; G02F 1/13357; C03C 3/091; G02B 6/12; C03C 3/085; G02B 6/13

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & Keywords: light guide plate, glass, plastic, composite sheet, face, coplanar

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2014-0340935 A1 (HON HAI PRECISION INDUSTRY CO., LTD.) 20 November 2014 See paragraphs 23-29 and figures 5-7.	1-15, 21-41
Y	US 2015-0368146 A1 (CORNING INCORPORATED) 24 December 2015 See paragraphs 2-9, 34-131 and figures 1-12.	1-15, 21-41
Y	WO 2015-081436 A1 (POLYVALOR, LIMITED PARTNERSHIP) 11 June 2015 See paragraph 61, claim 3 and figure 1-4.	34-41
A	US 2007-0221865 A1 (CHOONG-YONG SOHN et al.) 27 September 2007 See claims 1-8 and figures 1-4.	1-15, 21-41
A	KR 10-2004-0057383 A (LG.PHILIPS LCD CO., LTD.) 02 July 2004 See claims 1-7 and figures 8a-13.	1-15, 21-41



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

11 May 2017 (11.05.2017)

Date of mailing of the international search report

11 May 2017 (11.05.2017)

Name and mailing address of the ISA/KR

International Application Division

Korean Intellectual Property Office

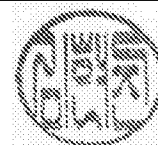
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2017/017338

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