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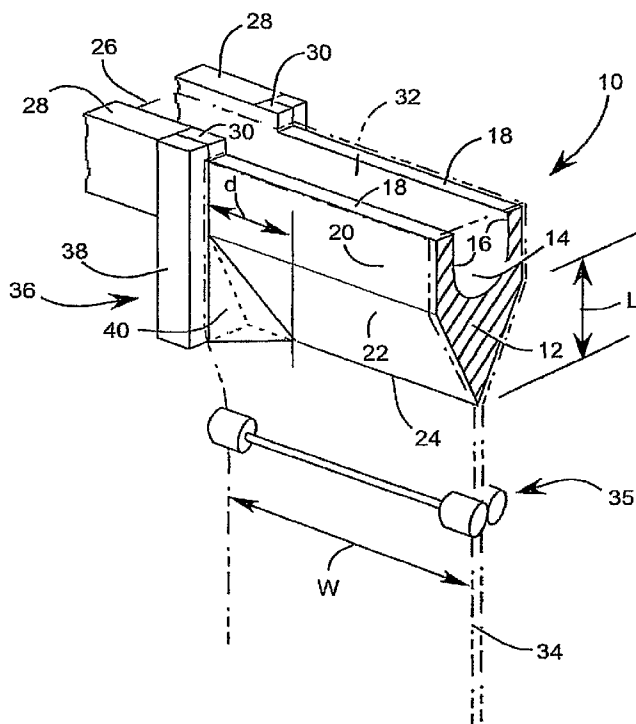
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(54) Title: APPARATUS AND METHOD FOR FORMING A GLASS SUBSTRATE WITH INCREASED EDGE STABILITY



(57) Abstract: An apparatus for forming glass substrates is presented wherein a design parameter of the apparatus, the vertical height L of converging forming surfaces which comprise the apparatus is related to the flow of molten glass over web portions of the apparatus.

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## **APPARATUS AND METHOD FOR FORMING A GLASS SUBSTRATE WITH INCREASED EDGE STABILITY**

### **BACKGROUND OF THE INVENTION**

#### **FIELD OF THE INVENTION**

[0001] The present invention relates generally to an apparatus for forming a glass substrate, and more particularly to a design criteria for the apparatus based on glass mass flow.

#### **TECHNICAL BACKGROUND**

[0002] Glass display panels in the form of liquid crystal displays (LCDs) are being used in an increasing variety of applications – from hand-held personal data assistants (PDAs) to computer monitors to television displays. These applications require glass sheets or substrates which have pristine, defect-free surfaces and consistent thickness. LCDs are comprised of at least several of these thin (e.g. < 0.7 mm) sheets of glass which are sealed together to form an envelope. The growing market for glass display panels, and in particular LCD display panels, has lead to an increasing demand for the thin glass substrates used in their manufacture.

[0003] One method of producing glass for optical displays is by an overflow downdraw process. U.S. Patent Nos. 3,338,696 and 3,682,609 (Dockerty), which are incorporated in their entirety herein by reference, disclose a fusion downdraw process which includes flowing a molten glass over the edges, or weirs, of a forming wedge, commonly referred to as an isopipe. The molten glass flows over converging forming surfaces of the isopipe, and the separate flows reunite at the apex, or root, where the two converging forming surfaces meet, to form a glass ribbon. Thus, the glass which has been in contact with the forming surfaces is located in the inner portion of the glass sheet, and the exterior surfaces of the glass ribbon are contact-free. Pulling rolls are placed downstream of the isopipe root and capture edge portions of the ribbon to adjust the rate at which the ribbon leaves the isopipe, and thus help determine the thickness of the finished sheet. As the glass ribbon descends from the root of the isopipe past the pulling rolls, it cools to form a solid, elastic glass ribbon, which may then be cut to form individual glass sheets, or substrates.

[0004] As the demand for display glass increases, manufacturers of glass substrates are faced with the need to increase production. One approach would be to install additional draws. However, this option involves considerable capital expenditure. A more cost effective approach is to increase the flow of glass for any given draw. However, flow increases typically require an increase in the size of the isopipe (e.g. isopipe width), to maintain a stable edge flow. The draw process itself is a delicate balance between a multitude of draw process conditions, and these process conditions may vary from individual draw to individual draw. Thus, simply increasing glass flow is often fraught with difficulty. Moreover, not only is the demand for glass substrates increasing, but display sizes are increasing steadily. This requires ever larger substrate sheets to maintain effective economies of scale. Consequently, both larger (e.g. wider) draws are needed as well as increased glass flow. What is needed is a design option that provides an ability to increase glass flow on a given draw without exceeding stability limits of the draw process, or to put in place large draw machines by scaling up from smaller, stable draws.

#### SUMMARY OF THE INVENTION

[0005] One embodiment of the present invention comprises an apparatus for forming a glass sheet comprising a forming wedge having a pair of downwardly inclined forming surface portions converging at a root of the forming wedge and having a vertical height of L above the root, an edge director extending along vertical edge portions of the forming surfaces, and including a web portion communicating with the forming surfaces for intercepting and thinning a flow of glass of G lbs/hour-inch over the web, and wherein  $G/L^3$  is greater than about 0.0017 lbs/hour/inch<sup>4</sup>. Preferably,  $G/L^3$  is greater than about 0.002 lbs/hour/inch<sup>4</sup>.

[0006] In another embodiment, a method of forming a glass substrate is disclosed comprising

[0007] flowing a molten glass over a forming wedge comprising a pair of downwardly inclined forming surface portions converging at a bottom of the forming wedge and forming a glass draw line therealong, and having a vertical height of L inches between the draw line and a horizontal plane intersecting tops of the inclined forming surface portions, an edge director including a web portion communicating with the forming surfaces for intercepting and thinning a flow of glass of G lbs/hour-inch over the web portion, and wherein  $G/L^3$  is greater than about 0.0017 lbs/hour/inch<sup>4</sup>.

[0008] Additional features and advantages of the invention 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 invention 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 embodiments of the invention, and are intended to provide an overview or framework for understanding the nature and character of the invention as it is claimed. The accompanying drawings are included to provide a further understanding of the invention, and are incorporated into and constitute a part of this specification. The drawings illustrate various embodiments of the invention, and together with the description serve to explain the principles and operations of the invention.

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

[0010] FIG. 1 is a partial cross sectional perspective view of one embodiment of the present invention showing one end of an apparatus comprising a forming wedge for fusion drawing a ribbon of glass.

[0011] FIG. 2 is a close up perspective view of the forming wedge of FIG. 1 showing the edge director and including the web portion of the edge director.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0012] Reference will now be made in detail to the present preferred embodiment of the invention, an example of which is illustrated in the accompanying drawings. Whenever possible, the same reference numerals will be used throughout the drawings to refer to the same or like parts.

[0013] Past experience with forming wedge design has tended to involve an iterative process. A forming wedge was designed, fabricated, and run in trials to assess its capability. An unstable forming wedge, e.g. one in which the edge-to-edge width of the glass sheet drawn from the forming wedge varied over time, would require modifications to the design and the fabrication of another forming wedge. This process continued until an appropriate combination of design features was arrived at. Nevertheless, edge stability could prove to be tenuous, as forming wedge geometry is subject to variation over time, as are various process variables, e.g. temperature distributions, glass flow variations, etc. The forming wedge itself is subject to extraordinarily harsh conditions, as the high temperature required for glass forming causes the forming wedge to sag or creep, over time, and the molten glass tends to slowly dissolve the material from which the forming wedge is fabricated, typically zircon. Thus, the performance of a particular forming wedge might prove to be sensitive to process conditions, leading to variations in edge stability. This is particularly true when an increase in forming wedge size is required.

[0014] One limitation to flat panel display size is the ability to form large sheets of pristine glass to serve as substrates for the display. While first generation glass sheets were less than a meter in size (e.g. width), present generation production is capable of forming pristine glass sheets several meters in width.

[0015] To accomplish this size increase, display glass manufacturers must increase the size, and particularly the width, of the forming wedge (isopipe). In the past, this usually progressed from the starting point of a prior generation forming wedge. This forming wedge was then used as a template for a subsequent, next generation forming wedge which was scaled in size from the prior generation.

[0016] Nevertheless, even when a forming wedge exhibiting relatively good edge stability formed the basis for a next generation design, scaling was often unsuccessful. For example, it was found that merely increasing the size (width) of the forming wedge without increasing

the size of the edge director web portions yielded an unstable edge flow, or at least an edge flow which was sensitive to process conditions. Thus, several forming wedges might need to be fabricated, while varying certain design parameters (e.g. width, trough geometry, etc.), before a larger, next generation forming wedge capable of providing a stable edge flow could be constructed and placed into production. As can be appreciated, this hit-or-miss approach to forming wedge design is undesirable.

[0017] Using the methods of the present invention not only allows the manufacture of a first forming wedge for the overflow downdraw forming of glass sheet with stable edge flow, but facilitates the deployment of different sized forming wedges scaled from the original forming wedge which also produce stable edge flow.

[0018] An apparatus 10 for the overflow down draw of pristine glass sheets according to the present invention is shown in FIG. 1. As illustrated in FIGs. 1-2, apparatus 10 comprises forming wedge 12 including an upwardly open channel 14 bounded on its longitudinal sides by wall portions 16, which terminate at their upper extent in opposed longitudinally-extending overflow weirs or lips 18. The weirs or lips 18 communicate with opposed outer sheet forming surfaces of forming wedge 12. As shown, forming wedge 12 is provided with a pair of substantially vertical forming surface portions 20 which communicate with lips 18, and a pair of downwardly inclined converging surface portions 22 which terminate at a substantially horizontal lower apex or root 24 forming a straight glass draw line.

[0019] Molten glass 26 is fed into channel 14 by means of delivery passage 28 communicating with channel 14. The feed into channel 14 may be single ended or, if desired, double ended. A pair of restricting dams 30 are provided above overflow lips 18 adjacent each end of channel 14 to direct the overflow of the free surface 32 of molten glass 26 over overflow lips 18 as separate streams, and down opposed forming surface portions 20, 22 to root 24 where the separate streams, shown in chain lines, converge to form a ribbon of virgin-surfaced glass 34. The ribbon is thereafter drawn by pulling rolls 35.

[0020] A pair of edge directors or correctors 36 is provided at each longitudinal end of the forming wedge so that an edge director extends along the vertical edge of each longitudinal end of the wedge on each side. Accordingly, four edge directors are provided for each forming wedge, with one at each corner of forming wedge 12. The edge directors 36 are comprised of two main portions, including a projecting edge surface portion 38 which

intersects the longitudinal ends of the forming surface portions of the wedge along their vertical extent, and a web or filleted portion 40 which extends between and communicates (intersects) with the projecting edge surface portion 38, and one of the downwardly inclined converging surface portions 22.

[0021] Web portion 40 intersects edge surface portion 38 along intersection line 42 between points A and B, and also intersects the inclined forming surface portion 22 along intersection line 44, between points A and C. Thus, intersection line 44 extends diagonally downward from point A to point C spaced inwardly from the projecting edge surface portion a distance  $d$  along root or apex 24 of the forming wedge 10. Similarly, intersection line 42 extends downward from point A to point B on edge surface portion 38. In some embodiments, point C may lie in the horizontal plane passing through root 24. However, in other embodiments, point C may lie either above or below the horizontal plane. The bottom edge 46 of web portion 40 extends from point B to point C. Bottom edge 46 may or may not be a straight line.

[0022] It was previously noted that, in accordance with the present embodiment, wedge member 10 comprised a plurality of edge directors. Specifically, a pair of edge directors 36 are provided on each side of the forming wedge, with one at each vertical corner so that two such edge directors are oppositely disposed at each longitudinal end of the forming wedge.

[0023] Molten glass flowing downwardly along edge portions of converging forming surfaces 22 is intercepted by web portions 40 along their diagonal lines of intersection 44 with the inclined forming surfaces 22. Edge portions of the downwardly flowing sheet are first guidably supported by the inclined forming surfaces, and then by web portions 40 of edge directors 36.

[0024] Web portions 40 provide a wetted length, which in a horizontal direction is greater than the length of the forming surface 22 which it intercepts, and effectively maximizes the width of usable sheet glass which can be obtained. Moreover, web portions 40 spread out or thin the glass flowing thereover, thus actually decreasing the thickness of the longitudinal edges of the molten glass stream before it leaves bottom edge 46 of the web portion.

[0025] The linear width of glass flowing over and contacting web portion 40 is shown in FIG. 2 and denoted by distance  $d$ , the distance inward of edge surface portion 38 of edge director 36 along root 24, as previously defined. The flow rate of this flow is designated  $G$  in lbs/hr

per inch of distance from edge surface portion 38 to point C. As there are typically four edge directors and four web portions, G is generally expressed as an average value of the mass flow rate over all the web portions.

[0026] As described above, the glass substrates made in a glass manufacturing system that uses the fusion process must have a uniform thickness to be used in devices like flat panel displays. To ensure this happens, the inventors have conducted studies and determined a way to enhance the fusion process so as to produce such glass substrates. In particular, the inventors have found that by managing the mass distribution of molten glass 26 which flows over the forming apparatus 10 one can have a direct impact on the quality/attributes of the glass substrates. As such, the subject of the present invention relates to the management of the mass flow rate of molten glass 26 that flows over forming apparatus 10.

[0027] It is known that an efficient fusion process results in a glass ribbon 34 that has a large area with a constant thickness. It is also desirable that the width of the ribbon does not vary during the drawing of the ribbon, i.e. that the edges of the ribbon remain stable. The inventors herein have determined that edge stability can be attained if the ratio of glass mass flow rate overflowing top surface 52 of web portion 40 (i.e. along distance d), to the vertical height L of the tops 50 of the converging forming surfaces 22 to the third power,  $L^3$ , that is the quantity  $G/L^3$ , is maintained equal to or greater than about 0.0017 lbs/hour/inch<sup>4</sup>, more preferably equal to or greater than about 0.002 lbs/hour-inch<sup>4</sup>.

[0028] It should be noted that while the condition outlined above is useful in establishing edge (ribbon width) stability in a fusion downdraw process, the ability to keep the tension forces exerted on the glass layer traveling over the web portion surface small is also beneficial. Forces involved include adhesive forces holding the glass on the web surface and the applied forces (gravity and pulling rolls 35) that pull the glass away from the edge director (web) surface. These forces attempt to pull the sheet off the edge director and can cause sheet width variation. It is therefore desirable to have the adhesion forces at least as great as the applied forces, and preferably significantly greater than the applied forces. Typically, edge directors comprise a refractory metal, such as platinum, in order to withstand the high glass forming temperatures (often in excess of 1000°C). It has been found that silicate glasses which are used for making display devices wet platinum poorly, in that the glass can completely separate from the platinum surface. Further, silicate glass is highly wetting on some ceramic materials, such as alumina or zircon. Thus, it may be advantageous to at least

coat the precious metal (e.g. platinum) web portions with a ceramic material such as alumina and/or zircon, to increase the adhesive forces. Alternatively, the web portions may be an integral (e.g. monolithic) part of the forming wedge, in that they are either cast or machined as a part of the forming wedge. The web portion may in some cases be manufactured as a separate ceramic component and later attached to the forming wedge. Advantages of machining the web portion as an integral or monolithic portion of the forming wedge is a reduction in the use of expensive precious metals, and the elimination of a surface disruption at the intersection of the forming wedge and the converging forming surfaces that may cause a glass flow disruption. In certain embodiments, the edge directors, and more particularly the web portion of the edge directors, and/or forming wedge may be fabricated either in part or in whole using any of the refractory materials described in U.S. Patent Application No. 60/640686, filed on December 30, 2004, the contents of which are incorporated herein by reference in their entirety. Examples of these materials include zircon, xenotime-type material, xenotime-stabilized zircon-type material, and a xenotime-stabilized zircon-type material plus a xenotime-type material, or combinations thereof, as defined and described in the aforementioned reference.

[0029] Of course it will be obvious to one skilled in the art that, given a forming edge with a stable edge flow (i.e. stable edge-to-edge width), the ability to scale to a larger forming wedge is facilitated by the present invention. That is, a subsequent forming wedge may be designed in accordance with the following criterion:

$$G = G_{\text{ref}}(L/L_{\text{ref}})^3 \quad (1)$$

Where G is the mass flow rate over the web portion of the subsequent forming wedge, and L is the vertical height of the converging forming surfaces of the subsequent forming wedge.  $G_{\text{ref}}$  and  $L_{\text{ref}}$  are those same parameters for the existing or previous forming wedge. As noted previously, G is typically represented as the average mass flow rate of all the web portions of a forming wedge.

[0030] It will be apparent to those skilled in the art that various modifications and variations can be made to the present invention without departing from the spirit and scope of the invention. Thus it is intended that the present invention cover the modifications and variations of this invention provided they come within the scope of the appended claims and their equivalents.

What is claimed is:

1. An apparatus for forming a glass sheet comprising:

a forming wedge (12) having a pair of downwardly inclined forming surface portions (22) converging at a root (24) of the forming wedge and having a vertical height of L above the root;

an edge director (36) extending along vertical edge portions of the forming surfaces, and including a web portion (40) communicating with the forming surfaces for intercepting and thinning a flow of glass of G lbs/hour-inch over the web; and

wherein  $G/L^3$  is greater than about 0.0017 lbs/hour/inch<sup>4</sup>.

2. The apparatus according to claim 1 wherein  $G/L^3$  is greater than about 0.002 lbs/hour/inch<sup>4</sup>.

3. The apparatus according to claim 1 wherein a surface of the web portion in contact with the flowing glass is a ceramic material.

4. The apparatus according to claim 3 wherein the web portion is a solid ceramic form.

5. The apparatus according to claim 4 wherein the web portion is a monolithic portion of the forming wedge.

6. The apparatus according to claim 3 wherein the ceramic material is selected from the group consisting of zircon, alumina, a xenotime-type material, a xenotime-stabilized zircon-type material, or combinations thereof.

7. The apparatus according to claim 3 wherein the web portion is comprised of ceramic coated refractory metal.

8. A method of forming a glass substrate comprising:

flowing a molten glass over a forming wedge (12) comprising a pair of downwardly inclined forming surface portions (22) converging at a bottom of the forming wedge and

forming a glass draw line (24) therealong, and having a vertical height of L inches between the draw line and a horizontal plane intersecting tops of the inclined forming surface portions, an edge director (36) including a web portion (40) communicating with the forming surfaces (22) for intercepting and thinning a flow of glass of G lbs/hour-inch over the web portion; and wherein  $G/L^3$  is greater than about 0.0017 lbs/hour/inch<sup>4</sup>.

9. The method according to claim 8 wherein  $G/L^3$  is greater than about 0.002 lbs/hour/inch<sup>4</sup>.

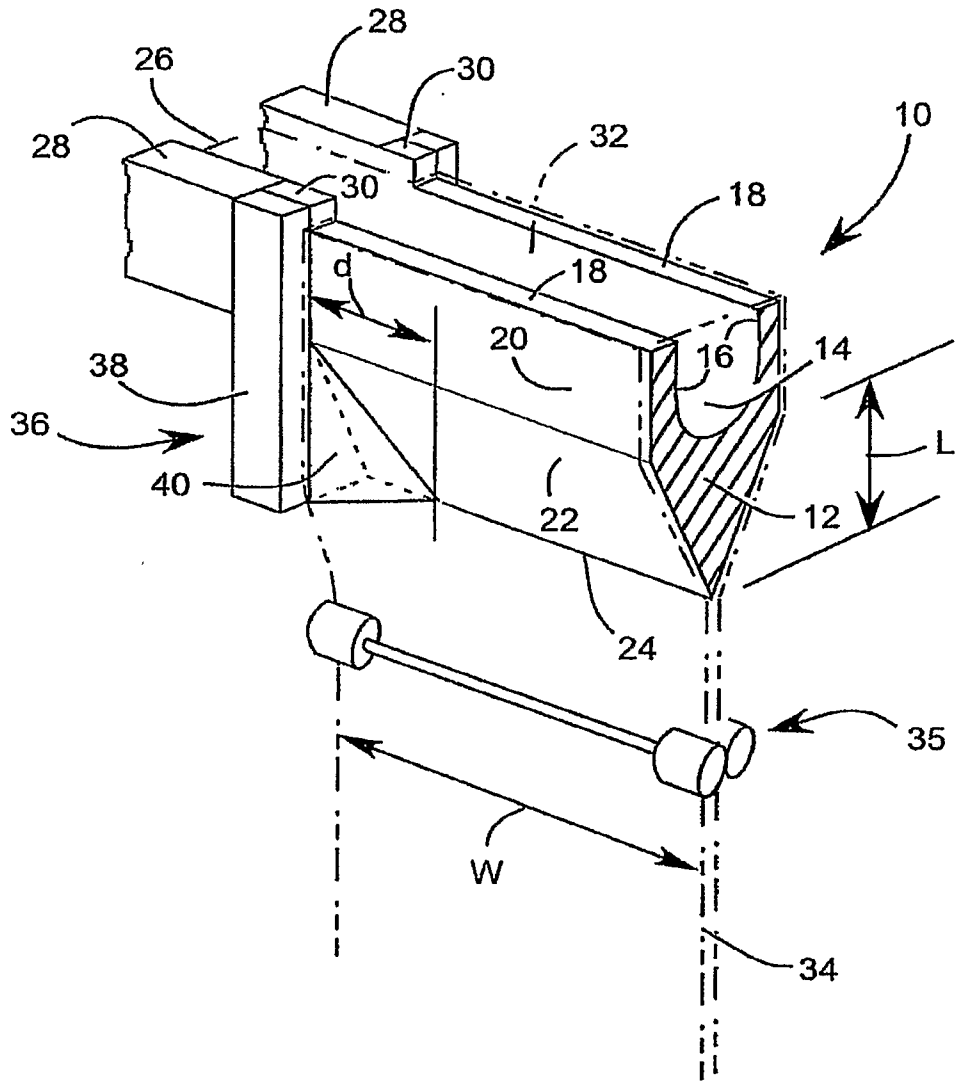


FIG. 1



# INTERNATIONAL SEARCH REPORT

International application No  
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**A. CLASSIFICATION OF SUBJECT MATTER**  
INV. C03B17/06

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)  
C03B

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

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

EPO-Internal

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

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X	US 3 451 798 A (SIMON RAPHAEL A) 24 June 1969 (1969-06-24) figures 1-5	1-9
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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
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- \*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.
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INTERNATIONAL SEARCH REPORT

International application No  
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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Information on patent family members

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