glass substrates (> 150 μm) can be fabricated with better puncture resistance, but these substrates lack suitable fatigue resistance and mechanical reliability upon bending.

Thus, there is a need for glass materials, components and assemblies for reliable use in flexible substrate and/or display applications and functions, particularly for flexible electronic device applications.

SUMMARY

[0006] A stack assembly is provided that comprises: a glass element having a thickness from about 25 μm to about 125 μm, a first primary surface, and a second primary surface, the glass element further comprising: (a) a first glass layer having a first primary surface; and (b) a compressive stress region extending from the first primary surface of the glass layer to a first depth in the glass layer, the region defined by a compressive stress of at least about 100 MPa at the first primary surface of the layer. The glass element is characterized by: (a) an absence of failure when the element is held at a bend radius from about 3 mm to about 20 mm for at least 60 minutes at about 25°C and about 50% relative humidity; (b) a puncture resistance of greater than about 1.5 kgf when the second primary surface of the element is supported by (i) an approximately 25 μm thick pressure-sensitive adhesive having an elastic modulus of less than about 1 GPa and (ii) an approximately 50 μm thick polyethylene terephthalate layer having an elastic modulus of less than about 10 GPa, and the first primary surface of the element is loaded with a stainless steel pin having a flat bottom with a 200 μm diameter; and (c) a pencil hardness of greater than or equal to 8H.

[0006a] In an aspect, there is provided a glass article, comprising: a glass element having a thickness from about 25 μm to about 125 μm, the glass element further comprising: (a) a first primary surface; (b) a second primary surface; and (c) a compressive stress region extending from the first primary surface of the glass element to a first depth in the glass element, the region defined by a compressive stress σI of at from 600 MPa to 1000 MPa at the first primary surface of the glass element, wherein the glass element is characterized by: (a) a stress profile such that when the glass element is bent to a target bend radius of from 1 mm to 5 mm, with the center of curvature on the side of the second primary surface so as to induce a bending stress σB at the first primary surface, $\sigma I + \sigma B < 0$; and (b) a puncture resistance of greater than about 1.5 kgf when the first primary surface of the glass element is loaded with a tungsten carbide ball having a diameter of 1.5 mm.

surface of the glass layer. The removing step can also be conducted such that the compressive stress region comprises a maximum flaw size of 2.5 μm or less, or even as low as 0.4 μm or less, at the first primary surface of the glass layer.

[0020a] In another aspect, there is provided a method of making a glass article, comprising the steps: forming a glass element having a thickness from about 25 μm to about 125 μm, the glass element further comprising: (a) a first primary surface; (b) a second primary surface; and (c) a compressive stress region extending from the first primary surface of the glass element to a first depth in the glass element, the region defined by a compressive stress σI of from 600 MPa to 1000 MPa at the first primary surface of the glass element, wherein the glass element is characterized by: (a) a stress profile such that when the glass element is bent to a target bend radius of from 1 mm to 5 mm, with the center of curvature on the side of the second primary surface so as to induce a bending stress σB at the first primary surface, $\sigma I + \sigma B < 0$; and (b) a puncture resistance of greater than about 1.5 kgf when the first primary surface of the glass element is loaded with a tungsten carbide ball having a diameter of 1.5 mm.

[0021] Additional features and advantages will be set forth in the detailed description which follows, and in part will be readily apparent to those skilled in the art from that description or recognized by practicing the embodiments as described herein, including the detailed description which follows, the claims, as well as the appended drawings.

[0022] It is to be understood that both the foregoing general description and the following detailed description are merely exemplary, and are intended to provide an overview or framework to understanding the nature and character of the claims. The accompanying drawings are included to provide a further understanding, and are incorporated in and constitute a part of this specification. The drawings illustrate one or more embodiments, and together with the description serve to explain principles and operation of the various embodiments. Directional terms as used herein—for example, up, down, right, left, front, back, top, bottom—are made only with reference to the figures as drawn and are not intended to imply absolute orientation.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] FIG. 1 is a perspective view of a stack assembly comprising a glass element with a glass layer according to an aspect of this disclosure.

[0024] FIG. 1A is perspective view of the stack assembly depicted in FIG. 1 subjected to bending forces.

[0025] FIG. 1B is a cross-sectional view of the stack assembly depicted in FIG. 1.

What is claimed is:

1. A glass article, comprising:

a glass element having a thickness from about 25 μm to about 125 μm, the glass element further comprising:

(a) a first primary surface;

(b) a second primary surface; and

(c) a compressive stress region extending from the first primary surface of the glass element to a first depth in the glass element, the region defined by a compressive stress σI of from 600 MPa to 1000 MPa at the first primary surface of the glass element,

wherein the glass element is characterized by:

(a) a stress profile such that when the glass element is bent to a target bend radius of from 1 mm to 5 mm, with the center of curvature on the side of the second primary surface so as to induce a bending stress σB at the first primary surface, $\sigma I + \sigma B < 0$; and

(b) a puncture resistance of greater than about 1.5 kgf when the first primary surface of the glass element is loaded with a tungsten carbide ball having a diameter of 1.5 mm.

2. The glass article of claim 1, wherein $\sigma I + \sigma B < 0$ to a depth of at least one micron below the first primary surface.

3. The article of claim 1 or claim 2, the glass element comprising (c) a pencil hardness of greater than or equal to 8H.

4. The article of any one of claims 1-3, the glass element comprising a plurality of layers.

5. The article of any one of claims 1-4, wherein when the first primary surface of the glass element is subject to a 1 kgf load from a Vickers indenter, there is introduced a flaw of ≤ 100 microns in the first primary surface.

6. The article of any one of claims 1-5, wherein the glass element has a Vickers hardness of 550 to 650 kgf/mm^2.

7. The article of any one of claims 1-6, wherein the glass element has a retained B10 bend strength of greater than 800 MPa after contact with a cube corner diamond indenter loaded with 10gf.

8. The article of any one of claims 1-7, comprising $F/w \leq 0.76$ N/mm, wherein F is the closing force to put the glass element at the target bend radius, and w is the dimension of the glass element in a direction parallel to the axis around which the glass is bent

9. The article of any one of claims 1-8, wherein the thickness of the glass element is from about 50 μm to about 100 μm.

10. The article of any one of claims 1-9, wherein the first depth is set at approximately one third of the thickness of the glass element or less from the first primary surface of the glass element.

11. The article of any one of claims 1-10, further comprising:

a second layer having a low coefficient of friction disposed on the first primary surface of the glass element.

12. The article of any one of claims 1-11, wherein the compressive stress region comprises a maximum flaw size of 5 μm or less at the first primary surface of the glass element.

13. The article of any one of claims 1-12, wherein the compressive stress region comprises a plurality of ion-exchangeable metal ions and a plurality of ion-exchanged metal ions, the ion-exchanged metal ions having an atomic radius larger than the atomic radius of the ion-exchangeable metal ions.

14. The article of any one of claims 1-13, wherein the glass element further comprises an edge, and an edge compressive stress region extending from the edge to an edge depth in the glass element, the edge compressive stress region defined by a compressive stress of at least about 100 MPa at the edge.

15. A foldable electronic device, comprising:

an electronic device having a foldable feature,

wherein the foldable feature comprises the glass article according to any one of claims 1-14.

16. A method of making a glass article, comprising the steps:

forming a glass element having a thickness from about 25 μm to about 125 μm, the glass element further comprising:

(a) a first primary surface;

(b) a second primary surface; and

(c) a compressive stress region extending from the first primary surface of the glass element to a first depth in the glass element, the region defined by a compressive stress σI of from 600 MPa to 1000 MPa at the first primary surface of the glass element,

wherein the glass element is characterized by:

(a) a stress profile such that when the glass element is bent to a target bend radius of from 1 mm to 5 mm, with the center of curvature on the side of the second primary surface so as to induce a bending stress σB at the first primary surface, $\sigma I + \sigma B < 0$; and

(b) a puncture resistance of greater than about 1.5 kgf when the first primary surface of the glass element is loaded with a tungsten carbide ball having a diameter of 1.5 mm.

17. The method of claim 16, wherein $\sigma I + \sigma B < 0$ to a depth of at least one micron below the first primary surface.

18. The method of claim 16 or claim 17, wherein the step of forming the glass element comprises a forming process selected from the group consisting of fusion, slot drawing, rolling, redrawing and float processes, the forming process further configured to form the glass element to the final thickness.

19. The method of any one of claims 16-18, wherein the step of forming the glass element comprises a forming process selected from the group consisting of fusion, slot drawing, rolling, redrawing and float processes, and a material removal process that removes material from the glass element to reach the final thickness.

20. The method of any one of claims 16-19, wherein the step of forming a compressive stress region extending from the first primary surface of the glass element to a first depth in the glass element comprises:

providing a strengthening bath comprising a plurality of ion-exchanging metal ions having an atomic radius larger in size than the atomic radius of a plurality ion-exchangeable metal ions contained in the glass element; and

submersing the glass element in the strengthening bath to exchange a portion of the plurality of ion-exchangeable metal ions in the glass element with a portion of the plurality of the ion-exchanging metal ions in the strengthening bath to form a compressive stress region extending from the first primary surface to the first depth in the glass element.

21. The method of claim 20, wherein the submersing step comprises submersing the glass element in the strengthening bath at about 400°C to about 450°C for about 15 minutes to about 180 minutes.

22. The method of claim 20, further comprising the step:

removing about 1 μm to about 5 μm from the final thickness of the glass element at the first primary surface after the step of forming the compressive stress region, wherein the removing step is conducted after the submersing the glass element step.

23. The method of any one of claims 16-22, wherein the compressive stress is from about 600 MPa to 1000 MPa.

24. The method of any one of claims 16-23, the glass element comprising a pencil hardness of greater than or equal to 8H.

25. The method of any one of claims 16-24, the glass element comprising a plurality of layers.

26. The method of any one of claims 16-25, wherein when the first primary surface of the glass element is subject to a 1 kgf load from a Vickers indenter, there is introduced a flaw of $\leq$ 100 microns in the first primary surface.

27. The method of any one of claims 16-26, wherein the glass element has a Vickers hardness of 550 to 650 kgf/mm^2.

28. The method of any one of claims 16-27, wherein the glass element has a retained B10 bend strength of greater than 800 MPa after contact with a cube corner diamond indenter loaded with 10gf.

29. The method of any one of claims 16-28, comprising $F/w \leq 0.76$ N/mm, wherein F is the closing force to put the glass element at the target bend radius, and w is the dimension of the glass element in a direction parallel to the axis around which the glass is bent