(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
06 February 2020 (06.02.2020)

WIPO | PCT

(10) International Publication Number
WO 2020/028024 A1

(51) International Patent Classification:
G06F 17/50 (2006.01)

(21) International Application Number:
PCT/US2019/041825

(22) International Filing Date:
15 July 2019 (15.07.2019)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
62/712,467 31 July 2018 (31.07.2018) US

(71) Applicant: **CORNING INCORPORATED** [US/US]; 1 Riverfront Plaza, Corning, New York 14831 (US).

(72) Inventors: **BABY, Shinu**; 3 Tall Meadows Court, Painted Post, New York 14870 (US). **HARRIS, Jason Thomas**; 305 Chelsea Court, Horseheads, New York 14845 (US). **PARK, Eunyoung**; 1F #39 Lane 50, Tianmu West Road, Taipei, 111 (TW). **QAROUSH, Yousef Kayed**; 6 Tara Place, Painted Post, New York 14870 (US). **ZOUBI, Sam Samer**; 132 Barrington Rd. N., Horseheads, New York 14845 (US).

(74) Agent: **SCHMIDT, Jeffrey A.**; Corning Incorporated, Intellectual Property Department, SP-TI-03-1, Corning, New York 14831 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ,

(54) Title: GLASS STACK MODULE FOR FLEXIBLE DISPLAY UNITS AND METHODS OF MANUFACTURING AND DESIGNING THE SAME

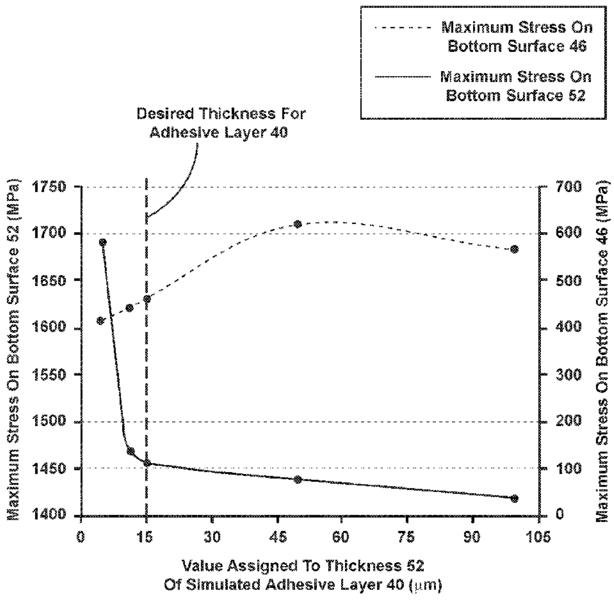


FIG. 7

(57) **Abstract:** A method of determining a desired thickness of an adhesive layer used to adhere a plurality of glass layers in a physical glass stack module comprising: designing a simulated glass stack module comprising a simulated adhesive layer adhering a first simulated glass layer to a second simulated glass layer; using a computer to repeatedly simulate a ball impacting a top surface of the first simulated glass layer, varying the thickness assigned to the simulated adhesive layer for each simulation; determining the maximum stress on one or more surfaces of the first simulated glass layer and the second simulated glass layer during impact; adding the maximum stresses together to determine a total maximum stress; and determining a desired thickness of the simulated adhesive layer that utilizes the lowest total maximum stress; wherein, the desired thickness is a thickness of an adhesive layer to be used in a physical glass stack module.

WO 2020/028024 A1

[Continued on next page]

OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:
- *with international search report (Art. 21(3))*
- *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

GLASS STACK MODULE FOR FLEXIBLE DISPLAY UNITS AND METHODS OF MANUFACTURING AND DESIGNING THE SAME

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of priority under 35 U.S.C. § 119 of U.S. Provisional Application Serial No. 62/712467 filed on July 31, 2018, the content of which is relied upon and incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] This disclosure generally relates to glass stack modules and various methods for manufacturing and designing them, including flexible and impact-resistant versions of the glass stack modules, for use in wearable and handheld display units.

BACKGROUND

[0003] Flexible versions of products and components that are traditionally rigid in nature are being conceptualized for new applications. For example, flexible electronic devices can provide thin, lightweight, and flexible properties that can translate into products that utilize curved displays, such as wearable devices. Many of these flexible electronic devices utilize flexible substrates for displays and for holding and mounting the electronic components of these devices. Relatively thick monolithic glass substrates can be bulky and do not sufficiently flex in order to be utilized in flexible devices. Failure of a glass substrate during flexure is a concern, caused by the bending of glass when the device is subjected to a dynamic load due to impact.

[0004] Polymer based cover substrates could be used in flexible displays or in wearable devices. However, they are prone to scratch, penetration, and impact damage. In addition, the optical clarity of polymer based cover substrates is much lower than the optical clarity of glass.

[0005] Thin, layered, and chemically strengthened glass substrates using optically clear adhesives provide balance between reliability, scratch and puncture resistance, flexibility, and optical clarity for lighter display units used in flexible electronic devices. However, there is a need to improve impact reliability of layered glass substrates during impact loading.

SUMMARY

[0006]According to a first aspect of the present disclosure, a method of using a computer to simulate the dropping of a ball onto a simulated glass stack module to determine a thickness of an adhesive layer to be used to adhere a plurality of glass layers in a physical glass stack module comprises: designing a simulated glass stack module comprising a first simulated glass layer, a second simulated glass layer, and a simulated adhesive layer disposed between the first simulated glass layer and the second simulated glass layer and adhering the first simulated glass layer to the second simulated glass layer; assigning a thickness to a first simulated glass layer, the thickness of the first simulated glass layer defined as a distance between a top surface and a bottom surface of the first simulated glass layer; assigning a thickness to a second simulated glass layer, the thickness of the second simulated glass layer defined as a distance between a top surface and a bottom surface of the second simulated glass layer; assigning a first thickness to the simulated adhesive layer; simulating the dropping of a ball on the simulated glass stack module, the ball having an assigned mass and radius, with the simulated ball dropping from an assigned height and impacting the top surface of the first simulated glass layer; determining the maximum stress on the bottom surface of the first simulated glass layer while the ball drops upon the simulated glass stack module; determining the maximum stress on the bottom surface of the second simulated glass layer while the ball is simulated to drop upon the simulated glass stack module; adding the maximum stress on the bottom surface of the first simulated glass layer and the maximum stress on the bottom surface of the second simulated glass layer to determine a total maximum stress; using the assigned thicknesses of the first simulated glass layer and the second simulated glass layer but using a plurality of thicknesses for the simulated adhesive layer, different than the first thickness, repeating the above steps after and including the simulating the dropping of the ball step to determine the total maximum stress for each thickness of the plurality of thicknesses of the simulated adhesive layer; and determining a desired thickness of the simulated adhesive layer that provides the lowest total maximum stress; wherein, the desired thickness is a thickness of an adhesive layer to be used to adhere a plurality of glass layers in a physical glass stack module.

[0007]In some embodiments of the first aspect, simulating the dropping of the ball on the simulated glass stack module includes simulating supporting the simulated glass stack module with a fixed support fixture that contacts a perimeter area of the bottom surface of the second

simulated glass layer but not a center of the bottom surface of the second simulated glass area. Simulating the supporting of the simulated glass stack module with the support fixture can assume frictionless hard contact between the bottom surface of the second simulated glass layer and the support fixture.

[0008]In some embodiments of the first aspect, the simulation of the ball impacting the top surface of the first simulated glass layer includes the ball impacting a center of the top surface of the first simulated glass layer.

[0009]In some embodiments of the first aspect, determining the maximum stress on the bottom surface of the first simulated glass layer and determining the maximum stress on the bottom surface of the second simulated glass layer collectively take into account an assigned elastic modulus and an assigned Poisson's ratio for each of the first simulated glass layer, the second simulated glass layer, and the simulated adhesive layer.

[0010]In some embodiments of the first aspect, simulating the dropping of the ball on the simulated glass stack module includes assuming that both the ball and the support fixture are rigid bodies.

[0011]In some embodiments of the first aspect, the thickness assigned to the first simulated glass layer is the same as the thickness assigned to the second simulated glass layer. Determining the maximum stress on the bottom surface of the first simulated glass layer and determining the maximum stress on the bottom surface of the second simulated glass layer can collectively take into account an assigned elastic modulus and an assigned Poisson's ratio for each of the first simulated glass layer, the second simulated glass layer, and the simulated adhesive layer.

[0012]In some embodiments of the first aspect, the plurality of thicknesses of the simulated adhesive layer and the first thickness of the simulated adhesive layer together include five or more different thicknesses ranging from 5 micrometers (μm or microns) to 100μm.

[0013]According to a second aspect of the present disclosure, a method of manufacturing a glass stack module comprises: determining a total combined thickness for a plurality of glass layers of a physical glass stack module; determining, via using a computer to simulate the dropping of a ball onto a simulated glass stack module, a thickness of one or more adhesive layers to be used to adhere the plurality of glass layers of the physical glass stack module by: designing the simulated glass stack module comprising a first simulated glass layer, a second simulated glass layer, and a simulated adhesive layer disposed between the first simulated glass layer and the second simulated glass layer and adhering the first simulated glass layer to the second simulated glass layer; assigning a thickness to the first simulated glass layer, the thickness of the first simulated glass layer defined as a distance between a top surface and a bottom surface of the first simulated glass layer; assigning a thickness to the second simulated glass layer, the thickness of the second simulated glass layer defined as a distance between a top surface and a bottom surface of the second simulated glass layer, the thickness of the first simulated glass layer and the thickness of the second simulated glass layer together equaling the total combined thickness of the plurality of glass layers of the physical glass stack module; assigning a first thickness to the simulated adhesive layer; simulating the dropping of a ball on the simulated glass stack module, the ball having an assigned mass and radius, with the ball dropping from an assigned height and impacting the top surface of the first simulated glass layer; determining a maximum stress on the bottom surface of the first simulated glass layer during simulating the dropping of the ball on the simulated glass stack module; determining a maximum stress on the bottom surface of the second simulated glass layer during simulating the dropping of the ball on the simulated glass stack module; adding the maximum stress on the bottom surface of the first simulated glass layer and the maximum stress on the bottom surface of the second simulated glass layer to determine a total maximum stress; using the assigned thicknesses of the first simulated glass layer and the second simulated glass layer but using a plurality of values for the thickness of the simulated adhesive layer, different than the first value of the thickness of the simulated adhesive layer, repeating the above steps after and including the simulating the dropping of a ball to determine the total maximum stress for each thickness of the plurality of values for the thickness of the simulated adhesive layer; and determining a desired thickness of the simulated adhesive layer that provides the lowest total maximum stress; and disposing an adhesive layer of the one or more adhesive layers between each of the plurality of glass layers, the adhesive layers so disposed each having a thickness equaling the desired thickness of the simulated adhesive layer, and wherein a cover layer and a base layer are the outer most layers of the plurality of glass layers.

[0014]In some embodiments of the second aspect, each of the plurality of glass layers has a thickness and the thickness of the base layer is the largest thickness of the plurality of glass layers. The cover layer can have a thickness and the thickness of the base layer is twice as thick, or thicker, as the thickness of the cover layer. The thickness of the base layer can be five times as thick, or thicker, as the thickness of the cover layer. A pressure sensitive sensor can be disposed between an intermediate glass layer of the plurality of glass layers and another glass layer of the plurality of glass layers.

[0015] In some embodiments of the second aspect, the thickness of the first simulated glass layer is the same as the thickness of the second simulated glass layer.

[0016] In some embodiments of the second aspect, the plurality values for the thicknesses of the simulated adhesive layer and the first value for the thickness of the simulated adhesive layer together include five or more different values ranging from 5μm to 100μm, and the thickness of each of the one or more adhesive layers is from 5μm to 100μm.

[0017] According to a third aspect of the present disclosure, an asymmetric glass stack module comprises: a first glass layer having a thickness and a bottom surface; a second glass layer having a thickness and facing the bottom surface of the first glass layer; an adhesive layer between the first glass layer and the second glass layer; wherein, the thickness of the second glass layer is greater than the thickness of the first glass layer; and wherein, the adhesive layer has a thickness predetermined to minimize maximum stress experienced by the first glass layer during an impact event.

[0018] In some embodiments of the third aspect, the thickness of the second glass layer is five or more times as thick as the thickness of the first glass layer.

[0019] In some embodiments of the third aspect, the glass stack module further comprises: an intermediate glass layer disposed between the first glass layer and the second glass layer, the intermediate glass layer having a thickness; a pressure sensitive sensor disposed on the intermediate glass layer; and a second adhesive layer adhering the intermediate glass layer to the second glass layer and the adhesive layer adhering the intermediate glass layer to the first glass layer; wherein, the second adhesive layer has a thickness equal to the thickness of the adhesive layer; and wherein, the thickness of the second glass layer is greater than the thickness of the intermediate glass layer.

[0020] 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.

[0021] 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

[0022]FIG. 1 is a view of a person holding a handheld computing device and wearing a wearable electronic device, both of which include a glass stack module with an exposed first glass layer;

[0023]FIG. 2 is a perspective view of some embodiments of the glass stack module of FIG. 1, illustrating a plurality of glass layers including a first glass layer and a second glass layer adhered together via an adhesive layer, and each of the first glass layer, the second glass layer, and the adhesive layer have a thickness;

[0024]FIG. 3A is a perspective view of some embodiments of the glass stack module of FIG. 1, illustrating the plurality of glass layers including the first glass layer, the second glass layer, an intermediate glass layer, and adhesive layers adhering the plurality of glass layers together;

[0025]FIG. 3B is an exploded perspective view of some embodiments of the glass stack module of FIG. 3A, illustrating sensors disposed between the first glass layer and the intermediate glass layer, and between the second glass layer and the intermediate glass layer respectively;

[0026]FIG. 4 is a perspective view of some embodiments of the glass stack module of FIG. 1, illustrating the plurality of glass layers including the first glass layer, the second glass layer, two intermediate glass layers, and adhesive layers adhering the plurality of glass layers together;

[0027]FIG. 5A is a perspective view of a simulated support fixture supporting a simulated glass stack module as part of a computer simulation of a ball dropping on the simulated glass stack module in order to ascertain maximum stress experienced by a first simulated glass layer and a second simulated glass layer of the simulated glass stack module;

[0028]FIG. 5B is a front view of the simulated support fixture supporting the simulated glass stack module taken along cross-section VB-VB of FIG. 5A, illustrating the simulated support fixture supporting a perimeter area of a bottom surface of the second simulated glass layer;

[0029]FIG. 6 is an elevational view of the simulated glass stack module of FIG. 5A, illustrating a simulated adhesive layer between the first simulated glass layer and the second simulated glass layer, each of the layers having a thickness;

[0030]FIG. 7 is a graph illustrating maximum stress experienced at a bottom surface of the first simulated glass layer of FIG. 5A and the bottom surface of the second simulated glass layer, as a function of the value assigned to the thickness of the simulated adhesive layer, during the computer simulating the dropping of the ball on the simulated glass stack module, to determine a desired thickness of the simulated adhesive layer that provided the lowest total maximum stress;

[0031]FIG. 8 is a graph illustrating the maximum principal stress experienced at the top surface of the first simulated glass layer of FIG. 5A as a function of the distance along a path (representing a distance from point of simulated impact) for the four different iterations of the computer simulating the dropping of the ball upon the simulated glass stack module, each iteration using the same total combined thickness for the first simulated glass layer and the second simulated glass layer but, for each subsequent iteration, decreasing the thickness of the first simulated glass layer and increasing the thickness of the second simulated glass layer;

[0032]FIG. 9 is a graph illustrating the maximum principal stress experienced at the bottom surface of the first simulated glass layer of FIG. 5A as a function of the distance along the path for the four different iterations of the computer simulating the dropping of the ball upon the simulated glass stack module;

[0033]FIG. 10 is a graph illustrating the maximum principal stress experienced at the top surface of the second simulated glass layer of FIG. 5A as a function of the distance along the path for the four different iterations of the computer simulating the dropping of the ball upon the simulated glass stack module;

[0034]FIG. 11 is a graph illustrating the maximum principal stress experienced at the bottom surface of the second simulated glass layer of FIG. 5A as a function of the distance along the path for the four different iterations of the computer simulating the dropping of the ball upon the simulated glass stack module; and

[0035]FIG. 12 is a graph illustrating the peak maximum principal stress experienced at each of the top surface of the first simulated glass layer, the bottom surface of the first simulated glass layer, the top surface of the second simulated glass layer, and the bottom surface of the second simulated glass layer as a function of the iteration of the computer simulation of the dropping of the ball using varying thicknesses for the first simulated glass layer and the second simulated glass layer, and illustrating the percentage change in the peak maximum principal stress as compared to the first iteration of the computer simulation.

DETAILED DESCRIPTION

[0036] Among other features and benefits, as described herein, improving the impact resistance of a glass stack module can be achieved by using a computer to simulate an impact event upon a glass stack module, with varying adhesive layer thicknesses, and determining resulting stresses upon various glass layers of the simulated glass stack module. The computer simulation reveals the thickness for the adhesive layer that results in the lowest stresses during impact, which can be the desired adhesive layer thickness actually utilized in the manufacture of a real (i.e., physical) glass stack module. The utilization of the desired adhesive layer thickness improves the impact resistance of the glass stack module. In addition, as described herein, further improvement to the impact resistance of the glass stack module is achieved through asymmetry of thicknesses of the glass layers of the glass stack module. In other words, the glass stack module with a base glass layer that is thicker than the other glass layers of the glass stack module increases the impact resistance of the glass stack module.

[0037] Referring now to FIG. 1, a glass stack module 10 is illustrated in use with a handheld computing device 12, which may be a smart phone, and a wearable electronic device 14, which may be a watch or smart watch. The glass stack module 10 is generally flexible to allow for use with devices with a curved interface such as the wearable electronic device 14. In some embodiments, the glass stack module 10 can be utilized with a device (not illustrated) that folds upon itself.

[0038] Referring now additionally to FIG. 2, the glass stack module 10 includes a plurality of glass layers 16. Among the plurality of glass layers 16 include a first glass layer 18 and a second glass layer 20. The first glass layer 18 and the second glass layer 20 can be the outermost layers of the plurality of glass layers 16, with the first glass layer 18 as a cover layer covering the remainder of the plurality of glass layers 16, and the second glass layer 20 as the base layer (i.e., the bottommost layer of the plurality of glass layers 16). The first glass layer 18, as the cover layer, can in some embodiments be touched during an intended use, such as with the wearable electronic device 14 or handheld computing device 12.

[0039] Referring now to FIGS. 3A, 3B, and 4, in some embodiments, the plurality of glass layers 16 of a glass stack module 10A includes an intermediate glass layer 22 disposed between the first glass layer 18 and the second glass layer 20. In some embodiments, the plurality of glass layers 16 of a glass stack module 10B includes several intermediate glass layers 22 disposed between the first glass layer 18 and the second glass layer 20. It should be understood that the plurality of glass layers 16 can include any number of intermediate glass layers 22. As illustrated in FIG. 3B, the intermediate glass layer 22, as well as the second glass layer 20, can support a sensor 24, which can be a pressure sensitive sensor, a capacitive sensor, or any type of sensor utilizable in a touch screen interface for a computing device. In other words, the sensor 24 can be disposed on any one of the intermediate glass layers 22 or the second glass layer 20.

[0040]The glass stack modules 10, 10A, 10B include one or more adhesive layers 26. The one or more adhesive layers 26 adhere the plurality of glass layers 16 to each other to form the glass stack modules 10, 10A, 10B. For example, in some embodiments of FIG. 2, the adhesive layer 26 is disposed between the first glass layer 18 and the second glass layer 20, which adheres the first glass layer 18 to the second glass layer 20. Likewise, in some embodiments of FIGS. 3A and 3B, an adhesive layer 26a adheres the intermediate glass layer 22 to the first glass layer 18, and a second adhesive layer 26b adheres the intermediate glass layer 22 to the second glass layer 20. Further, in some embodiments of FIG. 4, the adhesive layers 26 adhere the plurality of glass layers 16 together. It should be understood that embodiments of the glass stack module 10 including a greater number of glass layers in the plurality of glass layers 16 will include a greater number of adhesive layers 26.

[0041]Each of the plurality of glass layers 16 has a thickness 28. For example, the first glass layer 18 (cover layer) has a thickness 28a. Likewise, the second glass layer 20 (base layer) has a thickness 28b. Each of the intermediate glass layers 22 have a thickness 28c. The plurality of glass layers 16 have a total combined thickness, which is the sum of each of the individual thicknesses 28 of each of the plurality of glass layers 16. For example, the total combined thickness of the plurality of glass layers 16 for the embodiments of FIG. 2 is the sum of the thickness 28a of the first glass layer 18 and the thickness 28b of the second glass layer 20. The total combined thickness of the plurality of glass layers 16 for the embodiments of FIGS. 3A and 3B, is sum of the thickness 28a of the first glass layer 18, the thickness 28c of the intermediate glass layer 22, and the thickness 28b of the second glass layer 20.

[0042]Similarly, each of the adhesive layers 26 has a thickness 30. For example, the adhesive layer 26 of the embodiments of FIG. 2 has the thickness 30, the adhesive layers 26a, 26b of the embodiments of FIGS. 3A and 3B have respective thicknesses 30a, 30b.

[0043]Referring now to FIGS. 5A-6, described herein is a novel method of using a computer to simulate the dropping of a ball 32 onto a simulated glass stack module 34 to determine a desired thickness of the one or more adhesive layers 26 to be used to adhere the plurality of glass layers 16 together in the glass stack modules 10, 10A, 10B, such as the desired thickness of the adhesive layer 26 to be used to adhere the first glass layer 18 to the second glass layer 20 in the glass stack module 10. In performing the computer simulation of the dropping of the ball 32, the simulated glass stack module 34 is designed to have a first simulated glass layer 36, a second simulated glass layer 38, and a simulated adhesive layer 40. The simulated adhesive layer 40 is disposed between the first simulated glass layer 36 and the second simulated glass layer 38 and simulates adhering the first simulated glass layer 36 to the second simulated glass layer 38. The computer program Abaqus FEA (also referred to as ABAQUS) performs finite element analysis, among other things, and can be used with a computer to simulate the dropping of the ball 32 as described herein. The computer can be any computing device capable of performing the simulation of the dropping of the ball 32 as described herein, utilizing a computer program such as Abaqus FEA or other finite element analysis computer programs. The computer can utilize memory to store the computer program and a processor to execute the computer program, among other things.

[0044]The first simulated glass layer 36 is assigned a thickness 42. The thickness 42 is defined as a distance between a top surface 44 and a bottom surface 46 of the first simulated glass layer 36. Likewise, the second simulated glass layer 38 is assigned a thickness 48. The thickness 48 is defined as a distance between a top surface 50 of the second simulated glass layer 38 and a bottom surface 52 of the second simulated glass layer 38. In some embodiments of the method, the thickness 42 assigned to the first simulated glass layer 36 is the same as the thickness 48 assigned to the second simulated glass layer 38. For an initial simulation of the dropping of the ball 32, a first value for a thickness 54 (i.e., a “first thickness”) of the simulated adhesive layer 40 is assigned.

[0045]The simulation of the dropping of the ball 32 onto the simulated glass stack module 34 can include various assumptions that the computer performing the simulation takes into account. For example, it can be assumed that a (simulated) support fixture 56 supports the simulated glass stack module 34. The simulated support fixture 56 can take various forms. In the illustrated embodiments, the simulated support fixture 56 contacts a perimeter area 58 of the bottom surface 52 of the second simulated glass layer 38 while not contacting a center 60 of the bottom surface 52 of the second simulated glass layer 38. In addition, it can be assumed that the simulated support fixture 56 supports the simulated glass stack module 34 with frictionless hard contact between the bottom surface 52 of the second simulated glass layer 38 and the simulated support fixture 56. Further, it can be assumed that the simulated support fixture 56 includes a bottom surface 62, which is fixed in place (i.e., cannot move upon the simulated ball 32 dropping upon the simulated glass stack module 34). Further still, it can be assumed that the simulated ball 32 and the simulated support fixture 56 are rigid bodies.

[0046] An assigned mass and an assigned radius 64 are assigned to the simulated ball 32. The computer then simulates the dropping of the ball 32 onto the simulated glass stack module 34. The ball 32 is simulated to drop from an assigned height 66 and to impact the top surface 44 of the first simulated glass layer 36. In some embodiments of the simulation, the ball 32 impacts a center 68 of the top surface 44 of the first simulated glass layer 36. In the simulation, it can be assumed that the ball 32 impacts the top surface 44 of the first simulated glass layer 36 with frictionless hard contact.

[0047] In performing the computer simulation of the dropping of the ball 32, the maximum stress on the bottom surface 46 of the first simulated glass layer 36 while the ball 32 drops upon the simulated glass stack module 34 is determined. In addition, the maximum stress on the bottom surface 52 of the second glass layer 38 while the ball 32 drops upon the glass stack module 34 is determined. The determination of the maximum stresses can be made via finite element analysis. The determination of maximum stresses in the simulation can take into account assigned property values for the first simulated glass layer 36, the second simulated glass layer 38, and the simulated adhesive layer 40. For example, in the simulation, any one or more of an elastic modulus value and a Poisson’s ratio can be assigned to the first simulated glass layer 36, the second simulated glass layer 38, and the simulated adhesive layer 40.

[0048] In some embodiments, the method further includes determining a total maximum stress, which is the sum of the maximum stresses experienced at predetermined surfaces of the glass layers used in the simulation. In some embodiments, the total maximum stress is the sum of the maximum stress experienced at the bottom surface 46 of the first simulated glass layer 36 and the maximum stress experienced at the bottom surface 52 of the second simulated glass layer 38. In other embodiments, the total maximum stress could further include maximum stress experienced at one or more of the top surface 44 of the first simulated glass layer 36, the bottom surface 46 of the first simulated glass layer 36, the top surface 50 of the second simulated glass layer 38, and the bottom surface 52 of the second simulated glass layer 38.

[0049]The computer then repeats the simulation of the dropping of the ball 32, with each repeated simulation varying the value assigned to the thickness 54 of the simulated adhesive layer 40. In other words, the computer simulation of the dropping of the ball 32 is repeated using the assigned thicknesses 42, 48 of the first simulated glass layer 36 and the second simulated glass layer 38 respectively, but each simulation uses a different value for the thickness 54 of simulated adhesive layer 40 chosen from a plurality of values for the thickness 54 of the simulated adhesive layer 40 different than the first value for the thickness 54. The above steps, including in some embodiments the computer simulating the dropping of the ball 32 step to determine the total maximum stress for each value of the plurality of values for the thickness 54 of the simulated adhesive layer 40, are repeated.

[0050]The method further includes determining a desired thickness of the simulated adhesive layer 40 by evaluating the maximum stresses experienced at predetermined surfaces of the simulated glass layers used in the simulated glass stack module 34. In some embodiments, the desired thickness of the simulated adhesive layer 40 is determined by choosing which value of the plurality of values assigned as the thickness 54 of the simulated adhesive layer 40 resulted in the maximum stresses experienced at the predetermined surfaces of the simulated glass layers used in the simulation are simultaneously minimized or close to minimized. In some embodiments, the desired thickness of the simulated adhesive layer 40 is the thickness that provides the lowest total maximum stress. The determination can be made by choosing which value of the plurality of values assigned as the thickness 54 of the simulated adhesive layer 40 and the first value assigned as the thickness 54 of the simulated adhesive layer 40 resulted in the lowest total maximum stress. Such value for the thickness 54 of the simulated adhesive layer 40 is the desired thickness of the simulated adhesive layer 40. Alternatively, the determination can be made by interpolation from such data. In other words, the desired thickness of the simulated adhesive layer 40 can be a value different than the plurality of values assigned to be the thickness 54 of the simulated adhesive layer 40 for the repeated simulations. As explained further below, the desired thickness of the simulated adhesive layer 40 can subsequently be utilized as the thickness 30 of the one or more adhesive layers 26 that are actually used to adhere the plurality of glass layers 16 of the glass stack modules 10, 10A, 10B of the preceding embodiments of FIGS. 1-4. Using the desired thickness of the simulated adhesive layer 40 as the thickness 30 of the one or more adhesive layers 26 in the physical glass stack modules 10, 10A, 10B improves the impact resistance of the physical glass stack modules 10, 10A, 10B.

[0051]Referring now to FIG. 7, an example of the method is herein provided. In this example, as conveyed in the table below, the first simulated glass layer 36 and the second simulated glass layer 38 are each assigned an elastic modulus of 73.6GPa and a Poisson's ratio of 0.22. The first simulated glass layer 36 and the second simulated glass layer 38 are each assigned a value of 150µm for their respective thicknesses 42, 48. The simulated adhesive layer 40 is assigned an elastic modulus of 1.8GPa and a Poisson's ratio of 0.45. The ball 32 is assigned a mass of 100g and a radius 64 of 20millimeters (mm). It is assumed that the ball 32 drops from a height 66 of 10 centimeters (cm) during the simulation.

Layer	Elastic Modulus (GPa)	Poisson's Ratio	Thickness (µm)
First simulated glass layer 36	73.6	0.22	150
Simulated adhesive layer 40	1.8	0.45	variable
Second simulated glass layer 38	73.6	0.22	150

[0052]The thickness 54 of the simulated adhesive layer 40 is assigned a first value of 5µm. The dropping of the ball 32 was simulated – and the maximum stresses experienced at the bottom surface 46 of the first simulated glass layer 36 and the bottom surface 52 of the second simulated glass layer 38 were determined. The simulation of the dropping of the ball 32 was then repeated, each time assigning a different value for the thickness 54 of the simulated adhesive layer 40 chosen from a plurality of values. Specifically, as detailed in the below table, the simulation of the dropping of the ball 32 was repeated four times after the initial simulation – one time with the thickness 54 of the simulated adhesive layer 40 being assigned a value of 10µm, a second time with the thickness 54 of the simulated adhesive layer 40 being assigned a value of 15µm, a third time with the thickness 54 of the simulated adhesive layer 40 being assigned a value of 50µm, and a fourth with the thickness 54 of the simulated adhesive layer 40 being assigned a value of 100µm.

Simulation Iteration Number	Value Assigned for Thickness 54 of Simulated Adhesive Layer 40 (µm)
1	5
2	10
3	15

4	50
5	100

[0053] The maximum stresses experienced at the bottom surface 46 of the first simulated glass layer 36 and the bottom surface 52 of the second simulated glass layer 38 were determined for each simulation of the dropping of the ball 32. The graphed results are illustrated at FIG. 7. The maximum stresses experienced at the bottom surface 46 of the firsts simulated glass layer 36 and the maximum stress experiences at the bottom surface 52 of the second simulated glass layer 38 are then evaluated to determine a desired thickness for the simulated adhesive layer 40. As one mode of evaluation, the maximum stress experienced at the bottom surface 46 of the first simulated glass layer 36 and the maximum stress experienced at the bottom surface 52 of the second simulated glass layer 38, for each simulation of the dropping of the ball 32, for each assigned value for the thickness 54 of the simulated adhesive layer 40, are added to determine the total maximum stress for each value assigned to the thickness 54 of the simulated adhesive layer 40. The value assigned for the thickness 54 of the simulated adhesive layer 40 that results in the lowest total maximum stress is then determined and is deemed to be the desired thickness for the simulated adhesive layer 40. From the graph illustrated in FIG. 7, it is apparent that the value of 15μm assigned to be the thickness 54 of the simulated adhesive layer 40 resulted in the lowest total maximum stress – i.e., lower than the total maximum stress that resulted from the values of 5μm, 10μm, 50μm, and 100μm assigned to be the thickness 54 of the simulated adhesive layer 40. In some embodiments, the lowest total maximum stress can be interpolated from the graphing of the maximum stress data and the thickness 54 for the simulated adhesive layer 40 concluded to be the desired thickness providing the lowest total maximum stress could be a value different than the plurality of values utilized for the simulations. It can be noted that the values assigned to be the thickness 54 of the simulated adhesive layer 40 for the simulations of the dropping of the ball 32 include five or more different values ranging from 5μm to 100μm. The resulting desired thickness, in this example 15μm, for the simulated adhesive layer 40 can then be utilized as the actual thickness 30 for the one or more adhesive layers 26 for the manufacturing of any of the physical embodiments of the glass stack modules 10, 10A, 10B, as explained further below. As another mode of evaluation, the graphed results at FIG. 7 demonstrate that the maximum stresses experienced at bottom surfaces 46 and 52 are both close to being minimized at the value of 15μm assigned to be the thickness 54 of the simulated adhesive layer 40 – resulting in the determination that

15μm is the desired thickness for the simulated adhesive layer 40. Using the discovered desired thickness for the simulated adhesive layer 40 as the actual thickness 30 for the one or more adhesive layers 26 for the physical glass stack modules 10, 10A, 10B improves the impact resistance of the glass stack modules 10, 10A, 10B.

[0054] Disclosed herein is a novel method of manufacturing the glass stack modules 10, 10A, 10B for a particular application, such as, for example, for use in the wearable electronic device 14. The method includes determining the total combined thickness for the plurality of glass layers 16 of the glass stack modules 10, 10A, 10B. As mentioned above, each glass layer of the plurality of glass layers 16 has a thickness 28 and the total combined thickness for the plurality of glass layers 16 is the sum of the thicknesses 28 of each glass layer of the plurality of glass layers 16. The total combined thickness can be a function of the intended use of the glass stack modules 10, 10A, 10B. In other words, the total combined thickness may depend on the particular application. For example, the total combined thickness for the plurality of glass layers 16 of the glass stack modules 10, 10A, 10B intended to be used in the wearable electronic device 14 can be different than the total combined thickness for the plurality of glass layers 16 of the glass stack modules 10, 10A, 10B intended to be used in the handheld computing device 12. In some embodiments, the total combined thickness of the plurality of glass layers 16 is approximately 300μm, such as 300μm. The total combined thickness, in other embodiments, may range from 100μm or more to 500μm or less, for example from 120μm or more to 480μm, from 140μm or more to 460μm, from 160μm or more to 440μm, from 180μm or more to 420μm, from 200μm or more to 400μm, from 220μm or more to 380μm, from 240μm or more to 360μm, from 250μm or more to 350μm, from 260μm or more to 340μm, from 280μm or more to 320μm, or from 290μm or more to 310μm.

[0055] The method of manufacturing the glass stack modules 10, 10A, 10B further includes determining, via using the computer to simulate the dropping of a ball 32 onto the simulated glass stack module 34, a desired thickness of the one or more adhesive layers 26 to be used to adhere the plurality of glass layers 16 of the glass stack modules 10, 10A, 10B. This determination is made according to the computer simulation method described above, with the exception that the thickness 42 assigned to the first simulated glass layer 36 and the thickness 48 assigned to the second simulated glass layer 38 together equals the total combined thickness of the plurality of glass layers 16 of the glass stack modules 10, 10A, 10B to be manufactured. For example, if the glass stack modules 10, 10A, 10B to be manufactured pursuant to the novel method of manufacturing the glass stack modules 10, 10A, 10B is determined to be 300μm, then the thickness 42 of the first simulated glass layer 36 and the thickness 48 of the second simulated glass layer 38 together equals 300μm. In some embodiments, the assigned thickness 42 of the first simulated glass layer 36 and the assigned thickness 48 of the second simulated glass layer 38 used in the computer simulations are the same (i.e., in this example, the assigned thickness 42 of the first simulated glass layer 36 would be half of 300μm – 150μm – as would be the assigned thickness 48 of the second simulated glass layer 38). The desired thickness of the simulated adhesive layer 40 that provides the lowest total maximum stress experienced at the bottom surface 46 of the first simulated glass layer 36 and the bottom surface 52 of the second simulated glass layer 38 (or any other combination of chosen surfaces, as mentioned above) is then determined via the method described above.

[0056]The method of manufacturing the glass stack modules 10, 10A, 10B further includes using a plurality of glass layers 16. The plurality of glass layers 16 includes the first glass layer 18 (i.e., the cover layer) and the second glass layer 20 (i.e., the base layer). The first glass layer 18 and the second glass layer 20 are the outermost layers of the plurality of glass layers 16.

[0057]The method of manufacturing the glass stack modules 10, 10A, 10B further includes disposing the adhesive layer 26 of the one or more adhesive layers 26 between each of the plurality of glass layers 16. Each adhesive layer 26 so disposed has a thickness 30 that equals the desired thickness of the simulated adhesive layer 40 determined from the computer simulations described above. In some embodiments, each adhesive layer 26 so disposed has a thickness 30 of from 5μm to 100μm, for example from 10μm to 95μm, from 15μm to 90μm, from 20μm to 85μm, from 25μm to 80μm, from 30μm to 75μm, from 35μm to 70μm, from 40μm to 65m, from 45μm to 60μm, or from 50μm to 55μm. As discussed in greater detail below, the thickness 28b of the second glass layer 20 (i.e., the base layer) can be thicker than the thickness 28a of the first glass layer 18 (i.e., the cover layer). For example, in some embodiments, the thickness 28b of the second glass layer 20 (i.e., the base layer) is twice as thick, or thicker, as the thickness 28a of the first glass layer 18 (i.e., the cover layer). In some embodiments, the thickness 28b of the second glass layer 20 (i.e., the base layer) is five times as thick or thicker as the thickness 28a of the first glass layer 18 (i.e., the cover layer). The thickness of the second glass layer 20 (i.e., the base layer) can be the largest thickness of the plurality of glass layers 16.

[0058]In the event that the plurality of glass layers 16 includes the intermediate glass layer 22, the method of manufacturing the glass stack modules 10A, 10B can further include disposing a sensor 24 between the intermediate glass layer 22 of the plurality of glass layers 16 and another glass layer of the plurality of glass layers 16. As previously discussed in reference to FIG. 3B, the sensor 24 can be disposed between the intermediate glass layer 22 and the first glass layer 18 (i.e., the cover layer). The sensor 24 can be disposed on, such as adhered to, the intermediate glass layer 22 between the intermediate glass layer 22 and the first glass layer 18 (i.e., the cover layer).

[0059]Referring now to FIGS. 8-12, it has surprisingly been discovered that utilizing the plurality of glass layers 16 where the thickness 28 of each glass layer of the plurality of glass layers 16 are not identical, with the second glass layer 20 (i.e., the base layer) having the thickness 28b that is the most thick of the thicknesses 28 of the plurality of glass layers 16, reduces the maximum stress experienced by the top surface and bottom surface of each of the plurality of glass layers 16 (e.g., a top surface 70 of the first glass layer 18, see FIG. 2) (except for a bottom surface 72 of the second glass layer 20) during an impact event. The result is a glass stack module 10, 10A, 10B with the plurality of glass layers 16 having thicknesses 28 that are asymmetrical (not all identical) (thus the term “asymmetric glass stack module” as used herein). This discovery was confirmed through the computer simulation of dropping of the ball 32, as described above. Computer simulations simulating the dropping of the ball 32 on the simulated glass stack module 34 with varying thicknesses 42, 48 for the first simulated glass layer 36 and the second simulated glass layer 38, but keeping the total combined thickness of the first simulated glass layer 36 and the second simulated glass layer 38 constant, were conducted. For example, as illustrated in the table below, such computer simulations were conducted assigning (1) the thickness 42 of the first simulated glass layer 36 a value of 200μm and the thickness 48 of the second simulated glass layer 38 a value of 100μm; (2) the thickness 42 of the first simulated glass layer 36 a value of 150μm and the thickness 48 of the second simulated glass layer 38 a value of 150μm; (3) the thickness 42 of the first simulated glass layer 36 a value of 100μm and the thickness 48 of the second simulated glass layer 38 a value of 200μm; and (4) the thickness 42 of the first simulated glass layer 36 a value of 50μm and the thickness 48 of the second simulated glass layer 38 a value of 250μm.

Computer Simulation Iteration	Value Assigned to Thickness 42 of the First Simulated Glass Layer 36 (μm)	Value Assigned to Thickness 48 of the Second Simulated Glass Layer 38 (μm)	Value Assigned to Thickness 54 of the Simulated Adhesive Layer 40 (μm)
1	200	100	15

2	150	150	15
3	100	200	15
4	50	250	15

[0060]Note that the total combined thicknesses 42, 48 of the first simulated glass layer 36 and the second simulated glass layer 38 in each computer simulation was identical, i.e., 300μm. The value for the thickness 54 assigned to the simulated adhesive layer 40 was the same for each simulation – the desired thickness described in the example above of 15μm. For each computer simulation iteration, the maximum stresses along a path 74 defined as a distance from the point of impact (e.g., the center 68) of the ball 32 (see FIG. 5A) on each of the top surface 44 of the first simulated glass layer 36, the bottom surface 46 of the first simulated glass layer 36, the top surface 50 of the second simulated glass layer 38, and the bottom surface 52 of the second simulated glass layer 38 were plotted.

[0061]As illustrated in FIG. 8, in the simulations the maximum stress experienced at the top surface 44 of the first simulated glass layer 36 along the path 74 is generally less as the thickness 42 assigned to the first simulated glass layer 36 decreases and the thickness 48 assigned to the second simulated glass layer 38 increases. The computer simulation with the smallest value for the thickness 42 of the first simulated glass layer 36 and the largest value for the thickness 48 assigned to the second simulated glass layer 38 (i.e., computer simulation iteration 4, from the above table) generally provided the least maximum stress experienced at the top surface 44 of the first simulated glass layer 36 along the path 74.

[0062]As illustrated in FIG. 9, the maximum stress experienced at the bottom surface 46 of the first simulated glass layer 36 along the path 74 is generally less as the thickness 42 assigned to the first simulated glass layer 36 decreases and the thickness 48 assigned to the second simulated glass layer 38 increases. The computer simulation with the smallest value for the thickness 42 of the first simulated glass layer 36 and the largest value for the thickness 48 assigned to the second simulated glass layer 38 (i.e., computer simulation iteration 4, from the above table) generally provided the least maximum stress experienced at the bottom surface 46 of the first simulated glass layer 36 along the path 74.

[0063]As illustrated in FIG. 10, in the simulations the maximum stress experienced at the top surface 50 of the second simulated glass layer 38 along the path 74 is generally less as the thickness 42 assigned to the first simulated glass layer 36 decreases and the thickness 48 assigned to the second simulated glass layer 38 increases. The computer simulation with the smallest value for the thickness 42 of the first simulated glass layer 36 and the largest value for the thickness 48 assigned to the second simulated glass layer 38 (i.e., computer simulation iteration 4, from the above table) generally provided the least maximum stress experienced at the top surface 50 of the second simulated glass layer 38 along the path 74. Notably, as the value for the thickness 42 assigned to the first simulated glass layer 36 decreases and the value for the thickness 54 assigned to the second simulated glass layer 38 increases, the stress behavior experienced at the top surface 50 of the second simulated glass layer 38 changes from tensile stress to compressive stress, at least along a first portion of the path.

[0064]In contrast, as illustrated in FIG. 11, in the simulations the maximum stress experienced at the bottom surface 52 of the second simulated glass layer 38 along the path 74 is generally more as the thickness 42 assigned to the first simulated glass layer 36 decreases and the thickness 48 assigned to the second simulated glass layer 38 increases, again, at least along a first portion of the path. The computer simulation with the smallest value for the thickness 42 of the first simulated glass layer 36 and the largest value for the thickness 48 assigned to the second simulated glass layer 38 (i.e., computer simulation iteration 4, from the above table) generally provided the greatest maximum stress experienced at the bottom surface 52 of the second simulated glass layer 38 along the path 74. However, as illustrated in FIG. 12, the bottom surface 52 of the second simulated glass layer 38 experiences the largest peak maximum principal stress along the path 74 of any of the surfaces 44, 46, 50. Further, the percentage decrease in peak maximum principal stress along the path 74 experienced by the bottom surface 46 of the first simulated glass layer 36 and the top surface 50 of the second simulated glass layer 38 outweighs the percentage increase in peak maximum stress along the path 74 experienced by the bottom surface 52 of the second simulated glass layer 38, as the value assigned to the thickness 42 of the first simulated glass layer 36 decreases and the value assigned to the thickness 48 of the second simulated glass layer 38 increases. For example, when comparing computer simulation iteration 4 (50μm assigned as thickness 42 and 250μm assigned as thickness 48) to computer simulation iteration 1 (200μm assigned as thickness 42, and 100μm assigned as thickness 48), the peak maximum principal stress along the path 74 experienced by the bottom surface 46 of the first simulated glass layer 36 decreases by 74 percent and the peak maximum principal stress along the path 74 experienced by the top surface 50 of the second simulated glass layer 38 decreases by 78 percent, while the peak maximum stress along the path 74 experienced by the bottom surface 52 of the second simulated glass layer 38 increases by 34 percent.

[0065]These discoveries from the computer simulations can be translated into an improved impact resistant design of the physical glass stack modules 10, 10A, 10B manufactured pursuant to the method of manufacturing the glass stack modules 10, 10A, 10B described above. In other words, based on these surprising discoveries, the glass stack modules 10, 10A, 10B are asymmetric where the thickness 28b of the second glass layer 20 is greater than the thickness 28a of the first glass layer 18. The degree of asymmetry of thicknesses 28a, 28b can be selected to provide the desired stress level during an impact event experienced at a particular surface or surfaces of one or more of the plurality of glass layers 16, or the desired decreases in maximum stress experienced at a particular surface or surfaces of one or more of the plurality of glass layers 16. In other words, the degree of asymmetry of thicknesses 28a, 28b can be selected to provide a desired impact resistance profile. For example, the thickness 28b of the second glass layer 20 (i.e., the base layer) can be twice as thick as the thickness 28a of the first glass layer 18 (i.e., the cover layer) or thicker, as conceptualized in the computer simulation where the second simulated glass layer 38 was assigned a thickness 48 of 200μm and the first simulated glass layer 36 was assigned a thickness 42 of 100μm. As another example, the thickness 28b of the second glass layer 20 (i.e., the base layer) can be five or more times as thick as thickness 28a of the first glass layer 18 (i.e., the cover layer) or thicker, as conceptualized in the computer simulation where the second simulated glass layer 38 was assigned a thickness 48 of 250μm and the first simulated glass layer 36 was assigned a thickness 42 of 50μm. The thickness 28b of the second glass layer 20 (i.e., the base layer) can as thick, three times as thick, four times as thick, or any other multiple thickness as the thickness 28a of the first glass layer 18 (i.e., the cover layer).The adhesive layer 26 has a thickness 30, which as explained above can be predetermined to minimize the maximum stress experienced by the first glass layer 18, such as at a bottom surface 76 (see FIG. 2) thereof, during an impact event, to further improve impact resistance of the glass stack module.

[0066] In some embodiments, the intermediate glass layer 22 is disposed between the first glass layer 18 and the second glass layer 20, the intermediate glass layer 22 having the thickness 28c. Adhesive layer 26a adheres the intermediate glass layer 22 to the first glass layer 18. The second adhesive layer 26b adheres the intermediate glass layer 22 to the second glass layer 20. In accordance with the discussion above concerning the desired thickness of the adhesive layer 26 derived from the simulated adhesive layer 40, the thickness 30b of the second adhesive layer 26b, in some embodiments, is equal to the thickness 30a of the adhesive layer 26a, and both are the desired thickness derived from the simulated adhesive layer 40. In accordance with the discussion of asymmetric thicknesses for the plurality of glass layers 16 as discussed above, the thickness 28b of the second glass layer 20, in some embodiments, is thicker than the thickness 28c of the intermediate glass layer 22. In some embodiments, the thickness 28c of the intermediate glass layer 22 and the thickness 28a of the first glass layer 18 are the same. Utilizing a thickness 28b of the second glass layer 20 (the base layer) that is thicker than the thickness 28c of the intermediate glass layer 22 also lessens the stresses experienced by the intermediate glass layer 22, which is beneficial because the intermediate glass layer 22 often supports the sensor 24 and thus sensor 24 failure can be minimized. In some embodiments, the thickness of the second glass layer is larger than the thickness of the intermediate glass layer, and the thickness of the intermediate glass layer is larger than the thickness of the first glass layer.

[0067] It will be apparent to those skilled in the art that various modifications and variations can be made without departing from the spirit or scope of the claims.

[0068] As used herein, the term “about” means that amounts, sizes, formulations, parameters, and other quantities and characteristics are not and need not be exact, but may be approximate and/or larger or smaller, as desired, reflecting tolerances, conversion factors, rounding off, measurement error and the like, and other factors known to those of skill in the art. When the term “about” is used in describing a value or an end-point of a range, the disclosure should be understood to include the specific value or end-point referred to. Whether or not a numerical value or end-point of a range in the specification recites “about,” the numerical value or end-point of a range is intended to include two embodiments: one modified by “about,” and one not modified by “about.” 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.

[0069] 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 component" includes embodiments having two or more such components unless the context clearly indicates otherwise.

What is claimed is:

1. A method of using a computer to simulate the dropping of a ball onto a simulated glass stack module to determine a desired thickness of an adhesive layer to be used to adhere a plurality of glass layers in a physical glass stack module comprising:

designing a simulated glass stack module comprising a first simulated glass layer, a second simulated glass layer, and a simulated adhesive layer disposed between the first simulated glass layer and the second simulated glass layer and adhering the first simulated glass layer to the second simulated glass layer;

assigning a thickness to a first simulated glass layer, the thickness of the first simulated glass layer defined as a distance between a top surface and a bottom surface of the first simulated glass layer;

assigning a thickness to a second simulated glass layer, the thickness of the second simulated glass layer defined as a distance between a top surface and a bottom surface of the second simulated glass layer;

assigning a first value for a thickness of the simulated adhesive layer;

simulating the dropping of a ball on the simulated glass stack module, the ball having an assigned mass and radius, with the ball dropping from an assigned height and impacting the top surface of the first simulated glass layer;

determining a maximum stress on the bottom surface of the first simulated glass layer during simulating the dropping of the ball on the simulated glass stack module;

determining a maximum stress on the bottom surface of the second simulated glass layer during simulating the dropping of the ball on the simulated glass stack module;

adding the maximum stress on the bottom surface of the first simulated glass layer and the maximum stress on the bottom surface of the second simulated glass layer to determine a total maximum stress;

using the assigned thicknesses of the first simulated glass layer and the second simulated glass layer but using a plurality of values for the thickness of the simulated adhesive layer, different than the first value of the thickness of the simulated adhesive layer, repeating the above steps after and including simulating the dropping of the ball to determine the total maximum stress for each of the plurality of values for the thickness of the simulated adhesive layer; and determining a desired thickness of the simulated adhesive layer that results in the lowest total maximum stress;

wherein, the desired thickness is a thickness of an adhesive layer to be used to adhere a plurality of glass layers in a physical glass stack module.

2. The method of claim 1,

wherein, simulating the dropping of the ball on the simulated glass stack module includes simulation of supporting the simulated glass stack module with a support fixture that contacts a perimeter area of the bottom surface of the second simulated glass layer but not a center of the bottom surface of the second simulated glass layer.

3. The method of claim 2,

wherein, simulation of supporting the simulated glass stack module with the support fixture assumes frictionless hard contact between the bottom surface of the second simulated glass layer and the support fixture.

4. The method of claim 2 or claim 3,

wherein, the simulation includes a fixed bottom surface of the support fixture.

5. The method of any one of claims 1-4,

wherein, simulating the ball impacting the top surface of the first simulated glass layer includes the ball impacting a center of the top surface of the first simulated glass layer.

6. The method of any one of claims 1-5,

wherein, determining the maximum stress on the bottom surface of the first simulated glass layer and determining the maximum stress on the bottom surface of the second simulated glass layer collectively take into account an elastic modulus and a Poisson's ratio assigned to each of the first simulated glass layer, the second simulated glass layer, and the simulated adhesive layer.

7. The method of any one of claims 2-6,

wherein, simulating the dropping of the ball on the simulated glass stack module includes assuming that both the ball and the support fixture are rigid bodies.

8. The method of any one of claims 1-7,

wherein, the thickness assigned to the first simulated glass layer is the same as the thickness assigned to the second simulated glass layer.

9. The method of claim 8,

wherein, determining the maximum stress on the bottom surface of the first simulated glass layer and determining the maximum stress on the bottom surface of the second simulated glass layer collectively take into account an elastic modulus and a Poisson's ratio assigned to each of the first simulated glass layer, the second simulated glass layer, and the simulated adhesive layer.

10. The method of any one of claims 1-9,

wherein, the plurality of values for the thickness of the simulated adhesive layer and the first value for the thickness of the simulated adhesive layer together include five or more different values ranging from 5μm to 100μm.

11. A method of manufacturing a glass stack module comprising:

determining a total combined thickness for a plurality of glass layers of a physical glass stack module;

determining, via using a computer to simulate the dropping of a ball onto a simulated glass stack module, a desired thickness of one or more adhesive layers to be used to adhere the plurality of glass layers of the physical glass stack module by:

designing the simulated glass stack module comprising a first simulated glass layer, a second simulated glass layer, and a simulated adhesive layer disposed between the first simulated glass layer and the second simulated glass layer and adhering the first simulated glass layer to the second simulated glass layer;

assigning a thickness to the first simulated glass layer, the thickness of the first simulated glass layer defined as a distance between a top surface and a bottom surface of the first simulated glass layer;

assigning a thickness to the second simulated glass layer, the thickness of the second simulated glass layer defined as a distance between a top surface and a bottom surface of the second simulated glass layer, the thickness of the first simulated glass layer and the thickness of the second simulated glass layer together equaling the total combined thickness of the plurality of glass layers of the physical glass stack module;

assigning a first value for a thickness of the simulated adhesive layer;

simulating the dropping of the ball on the simulated glass stack module, the ball having an assigned mass and radius, with the ball dropping from an assigned height and impacting the top surface of the first simulated glass layer;

determining a maximum stress on the bottom surface of the first simulated glass layer during simulating the dropping of the ball on the simulated glass stack module;

determining a maximum stress on the bottom surface of the second simulated glass layer during simulating the dropping of the ball on the simulated glass stack module;

adding the maximum stress on the bottom surface of the first simulated glass layer and the maximum stress on the bottom surface of the second simulated glass layer to determine a total maximum stress;

using the assigned thicknesses of the first simulated glass layer and the second simulated glass layer but using a plurality of values for the thickness of the simulated adhesive layer, different than the first value of the thickness of the simulated adhesive layer, repeating the above steps after and including the simulating the dropping of the ball to determine the total maximum stress for each thickness of the plurality of values for the thickness of the simulated adhesive layer; and

determining a desired thickness of the simulated adhesive layer that results in the lowest total maximum stress; and

disposing an adhesive layer of the one or more adhesive layers between each of the plurality of glass layers, the adhesive layers so disposed each having a thickness equaling the desired thickness of the simulated adhesive layer.

12. The method of claim 11,

wherein, each of the plurality of glass layers has a thickness and the thickness of the base layer is the largest thickness of the plurality of glass layers.

13. The method of claim 12,

wherein, outermost layers of the plurality of glass layers comprise a cover layer and a base layer, and wherein the cover layer has a thickness and the thickness of the base layer is twice as thick, or thicker, as the thickness of the cover layer.

14. The method of claim 13,

wherein, the thickness of the base layer is five times as thick, or thicker, as the thickness of the cover layer.

15. The method of any one of claims 12-14 further comprising:

disposing a pressure sensitive sensor between an intermediate glass layer of the plurality of glass layers and another glass layer of the plurality of glass layers.

16. The method of any one of claims 11-15,

wherein, the thickness of the first simulated glass layer is the same as the thickness of the second simulated glass layer.

17. The method of any one of claims 11-16,

wherein, the plurality of values for the thickness of the simulated adhesive layer and the first value for the thickness of the simulated adhesive layer together include five or more different values ranging from 5µm to 100µm; and

wherein, the thickness of each of the one or more adhesive layers is from 5µm to 100µm.

18. An asymmetric glass stack module comprising:

a first glass layer having a thickness and a bottom surface;

a second glass layer having a thickness and facing the bottom surface of the first glass layer;

an adhesive layer between the first glass layer and the second glass layer;

wherein, the thickness of the second glass layer is greater than the thickness of the first glass layer; and

wherein, the adhesive layer has a thickness predetermined to minimize maximum stress experienced by the first glass layer during an impact event.

19. The asymmetric glass stack module of claim 18,

wherein, the thickness of the second glass layer is five or more times as thick as the thickness of the first glass layer.

20. The asymmetric glass stack module of claim 18 or claim 19, further comprising:

an intermediate glass layer disposed between the first glass layer and the second glass layer, the intermediate glass layer having a thickness;

a pressure sensitive sensor disposed on the intermediate glass layer; and

a second adhesive layer adhering the intermediate glass layer to the second glass layer, and the adhesive layer adhering the intermediate glass layer to the first glass layer;

wherein, the second adhesive layer has a thickness equal to the thickness of the adhesive layer; and

wherein, the thickness of the second glass layer is greater than the thickness of the intermediate glass layer.

FIG. 1

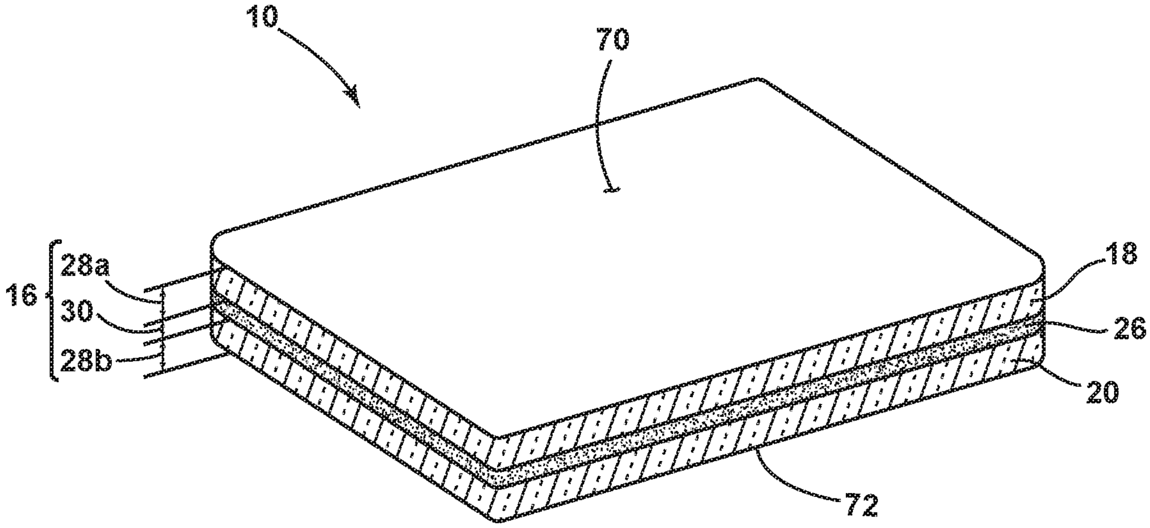


FIG. 2

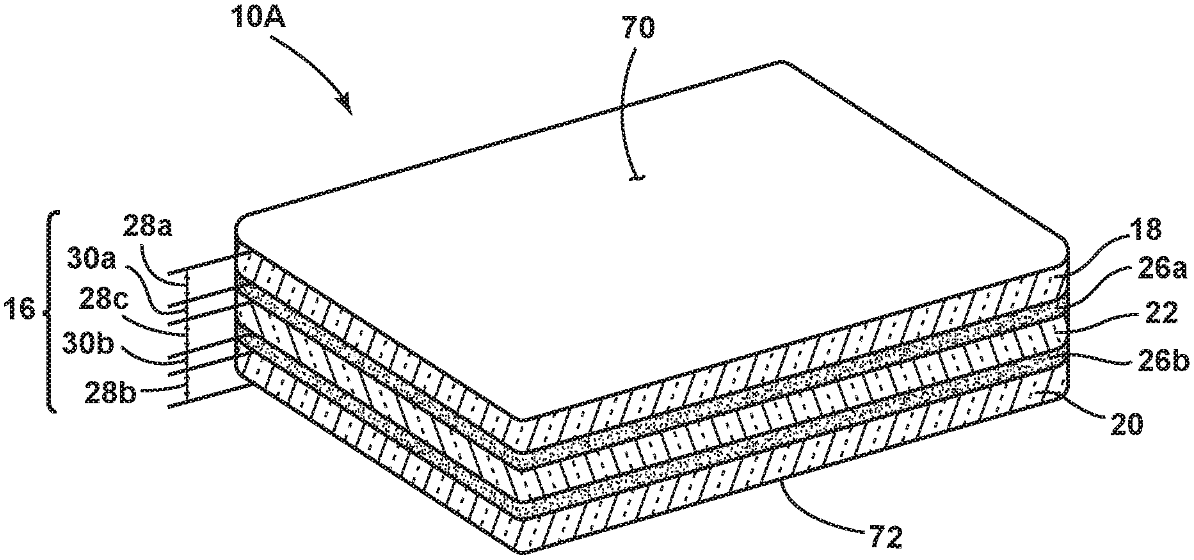


FIG. 3A

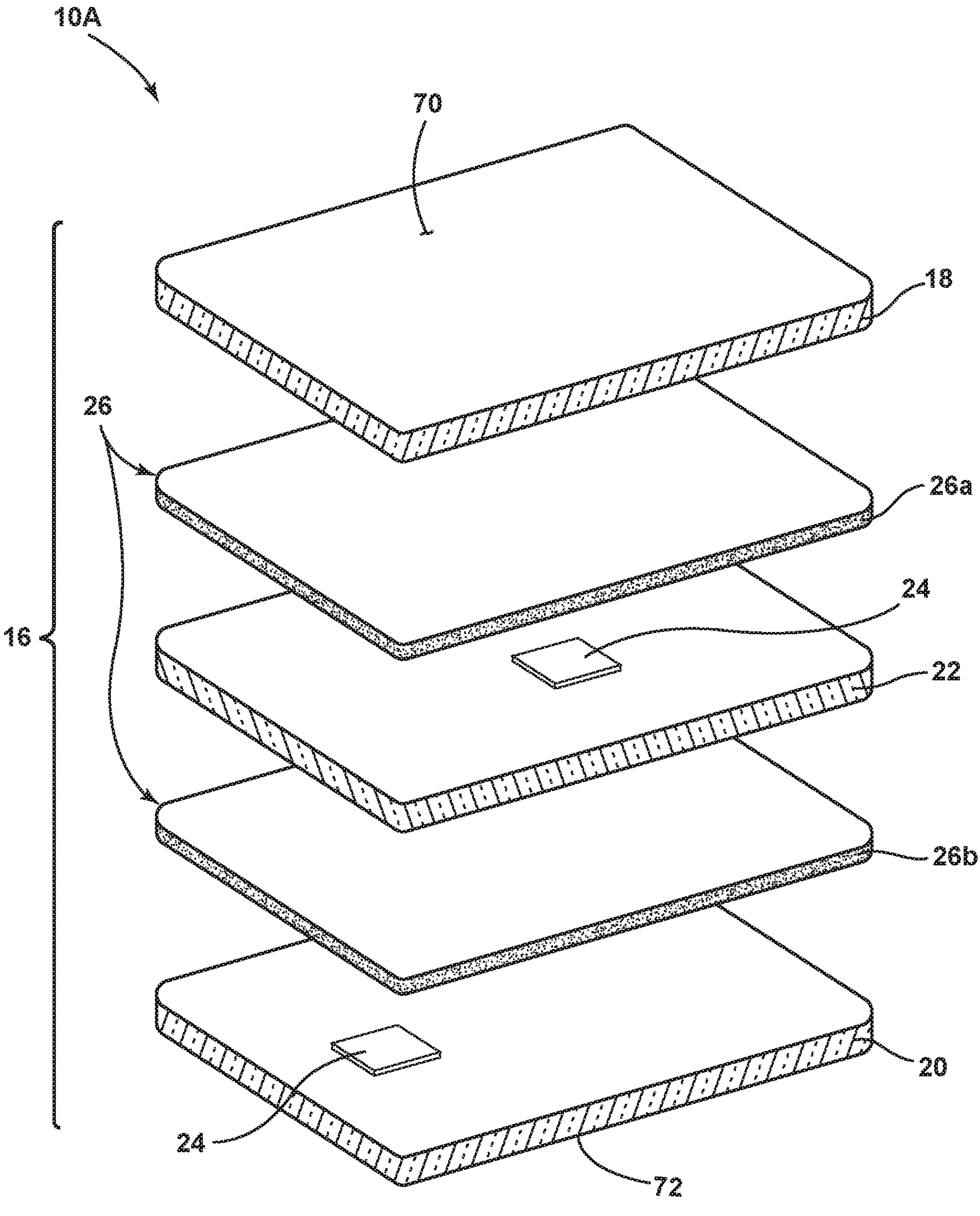


FIG. 3B

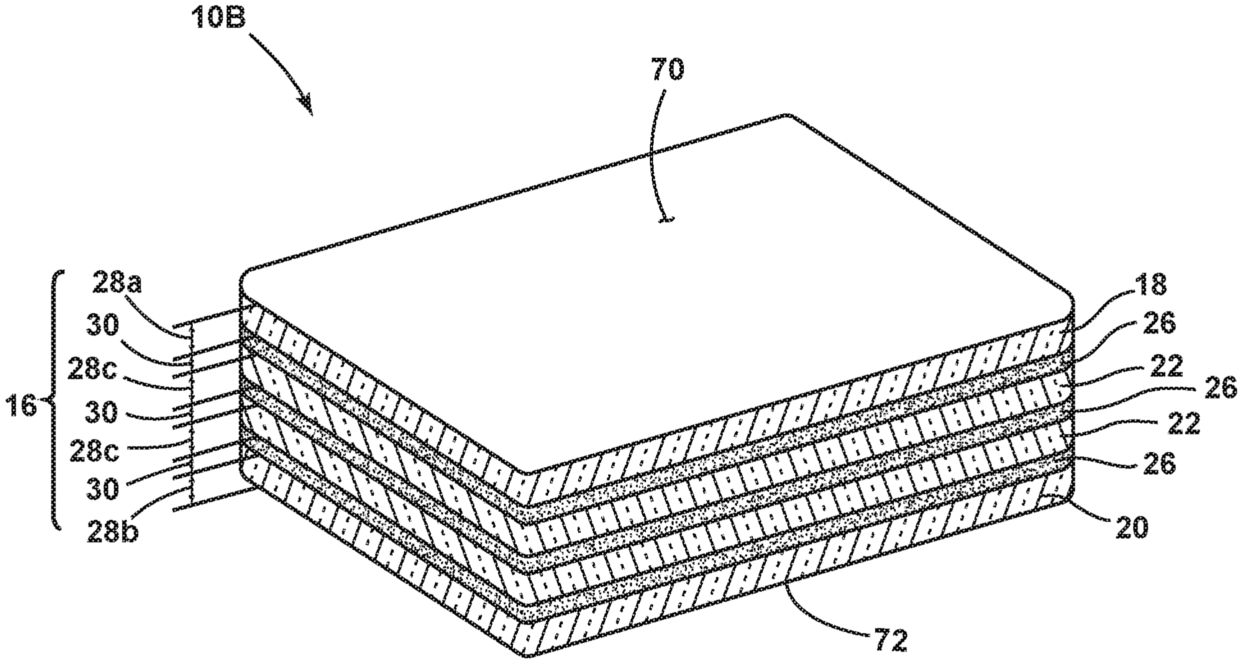


FIG. 4

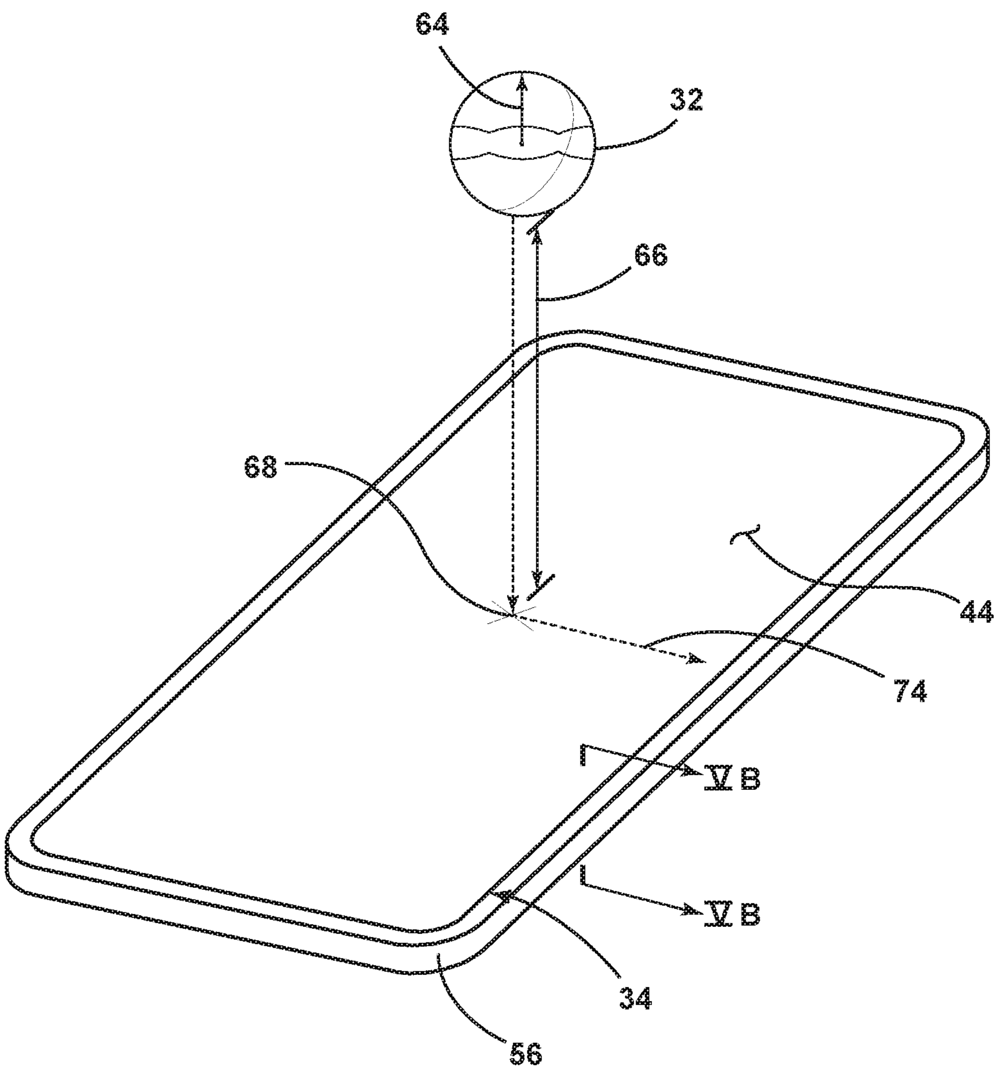


FIG. 5A

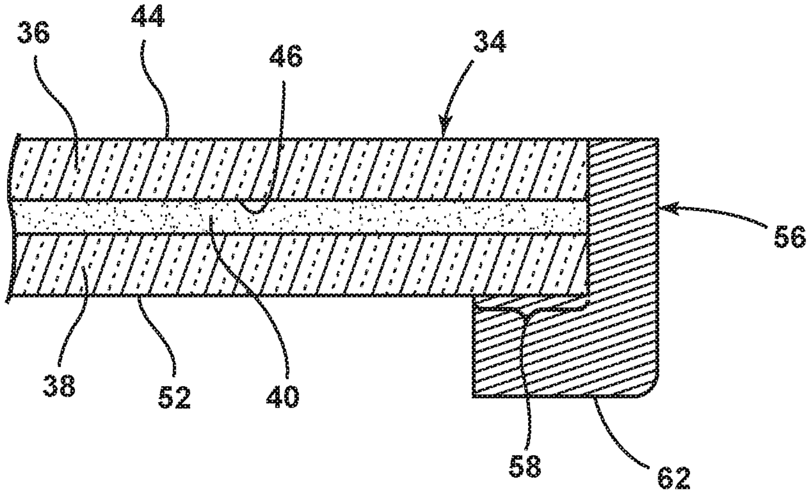


FIG. 5B

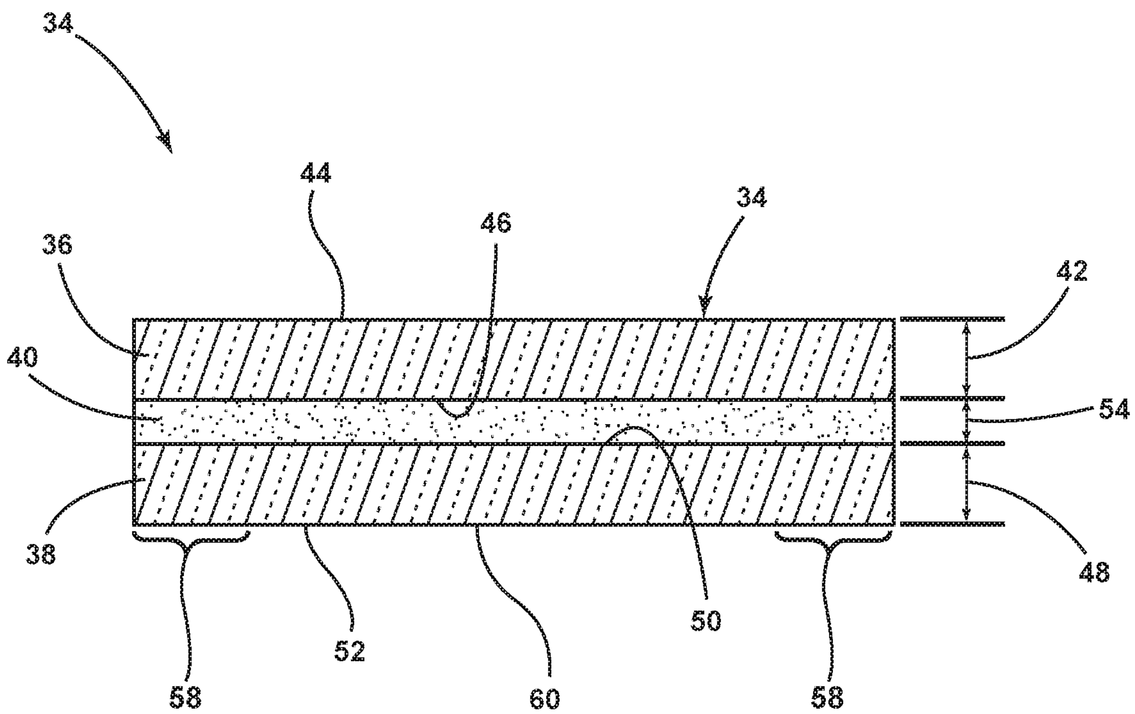


FIG. 6

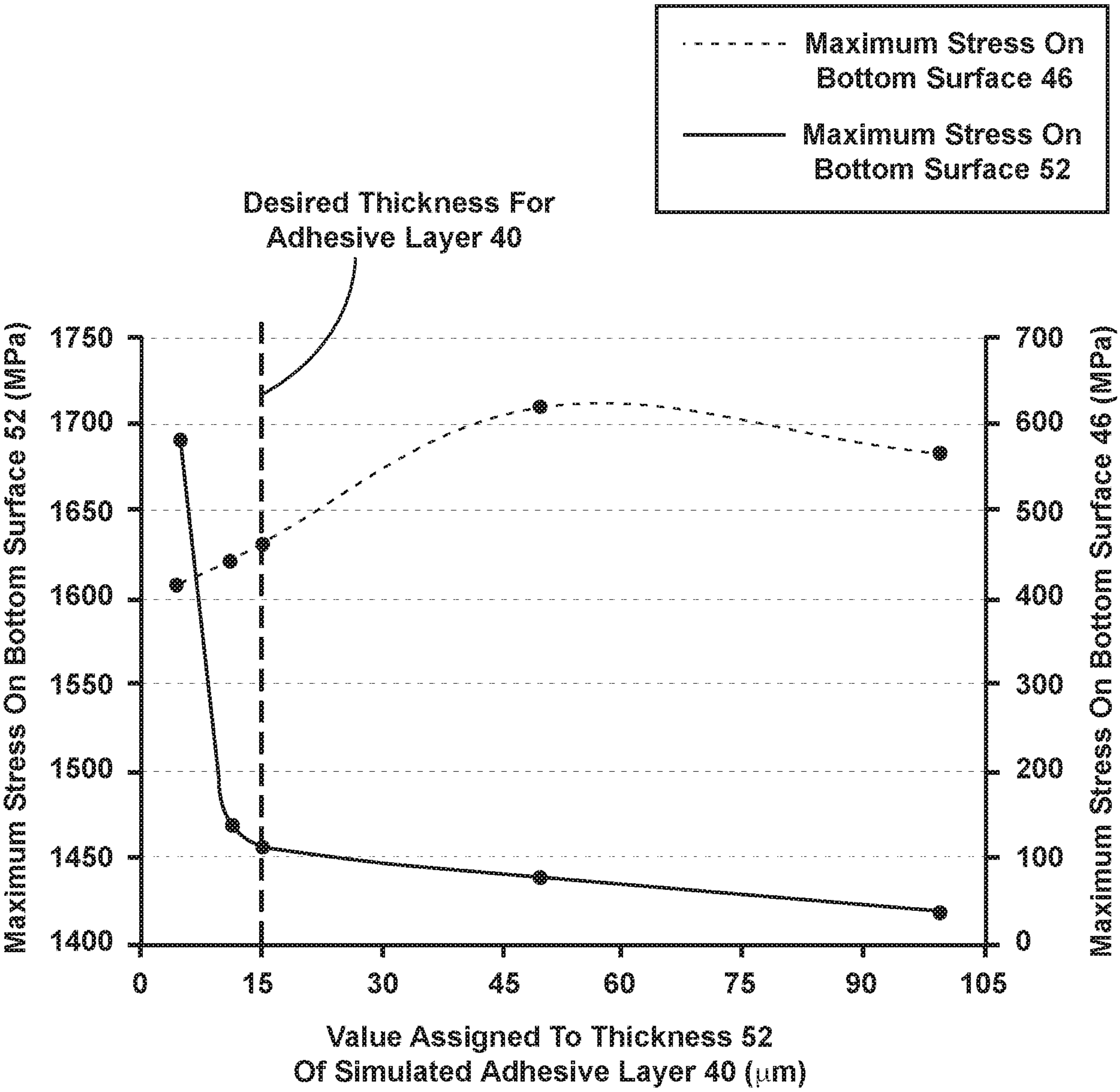

Maximum Stress On Bottom Surface 46
Maximum Stress On Bottom Surface 52
Desired Thickness For Adhesive Layer 40
Maximum Stress On Bottom Surface 52 (MPa)
1750
1700
1650
1600
1550
1500
1450
1400
Maximum Stress On Bottom Surface 46 (MPa)
700
600
500
400
300
200
100
0
0
15
30
45
60
75
90
105
Value Assigned To Thickness 52 Of Simulated Adhesive Layer 40 (μm)

FIG. 7

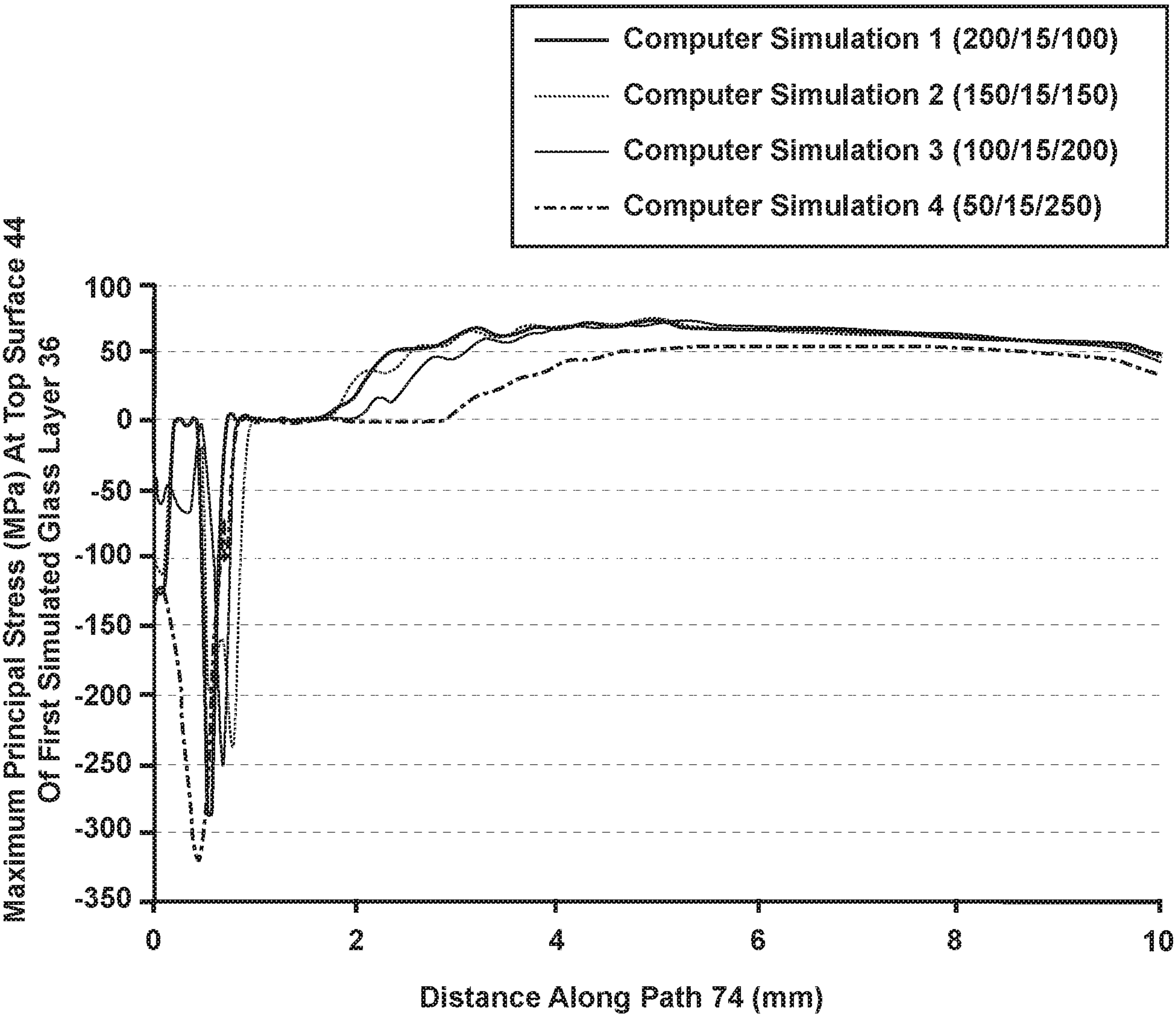
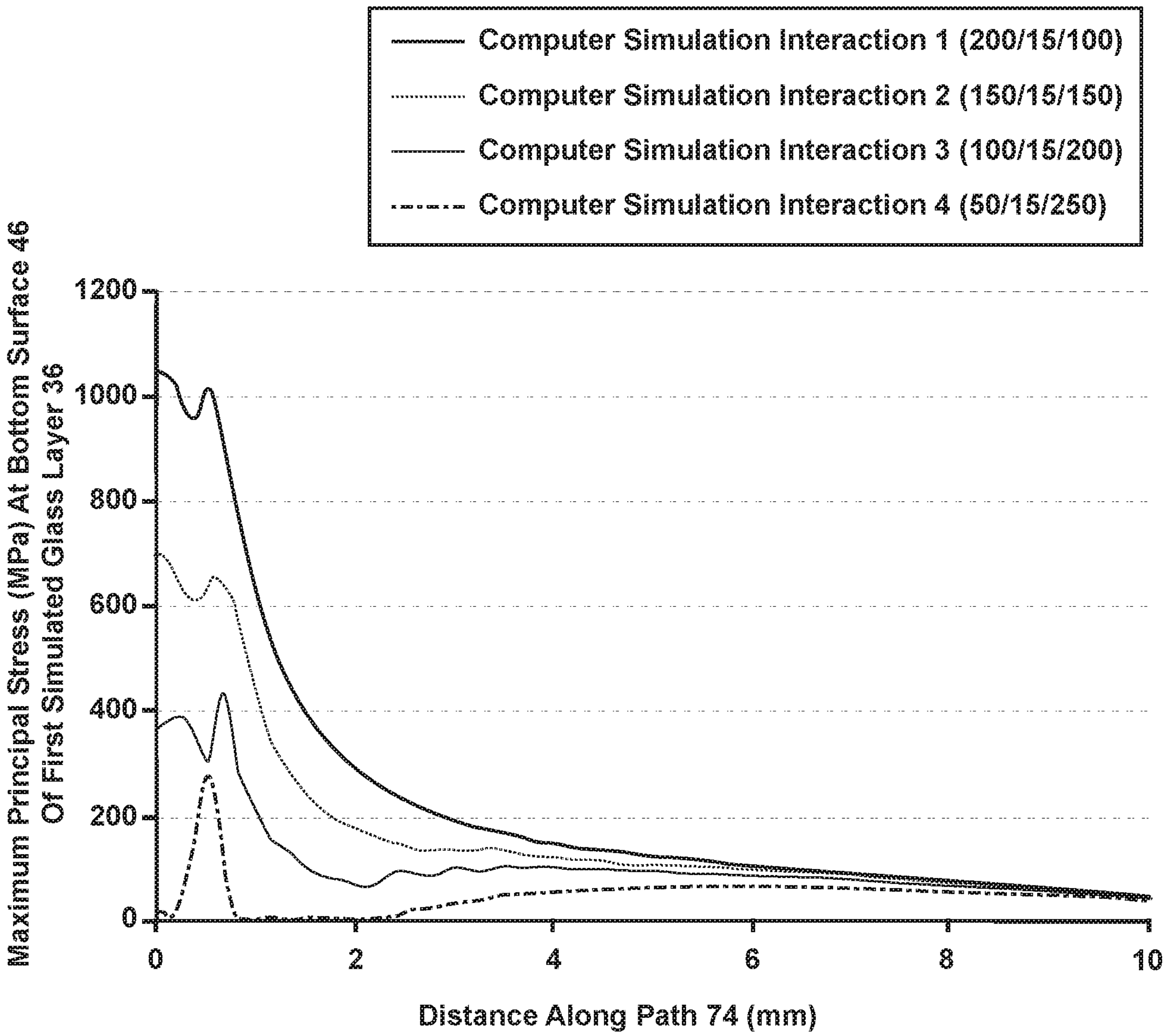
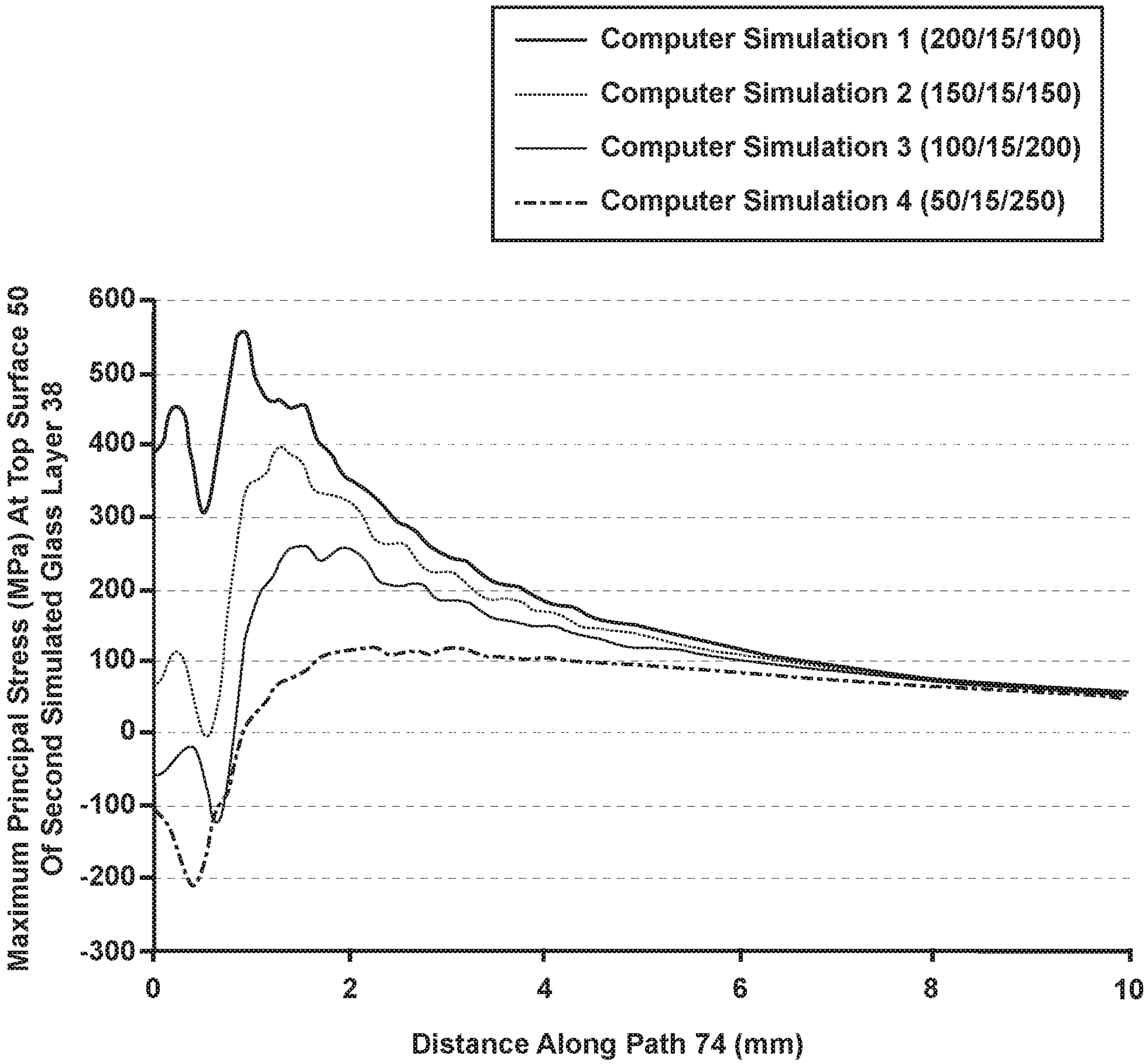

Computer Simulation 1 (200/15/100)
Computer Simulation 2 (150/15/150)
Computer Simulation 3 (100/15/200)
Computer Simulation 4 (50/15/250)
Maximum Principal Stress (MPa) At Top Surface 44
Of First Simulated Glass Layer 36
100
50
0
-50
-100
-150
-200
-250
-300
-350
0
2
4
6
8
10
Distance Along Path 74 (mm)

FIG. 8



Computer Simulation Interaction 1 (200/15/100)
Computer Simulation Interaction 2 (150/15/150)
Computer Simulation Interaction 3 (100/15/200)
Computer Simulation Interaction 4 (50/15/250)
Maximum Principal Stress (MPa) At Bottom Surface 46 Of First Simulated Glass Layer 36
1200
1000
800
600
400
200
0
0
2
4
6
8
10
Distance Along Path 74 (mm)

FIG. 9



Computer Simulation 1 (200/15/100)
Computer Simulation 2 (150/15/150)
Computer Simulation 3 (100/15/200)
Computer Simulation 4 (50/15/250)
Maximum Principal Stress (MPa) At Top Surface 50 Of Second Simulated Glass Layer 38
600
500
400
300
200
100
0
-100
-200
-300
0
2
4
6
8
10
Distance Along Path 74 (mm)

FIG. 10

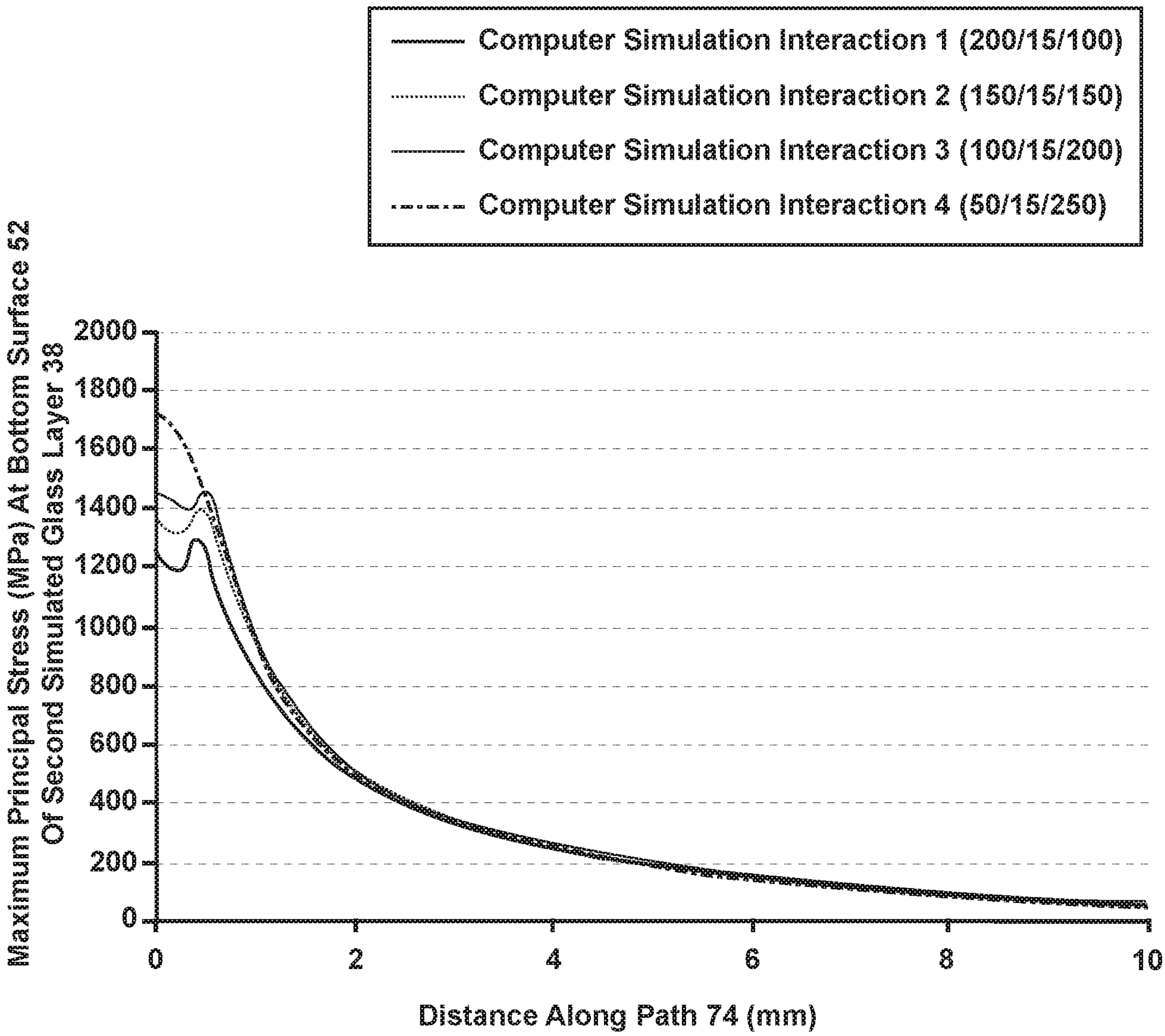
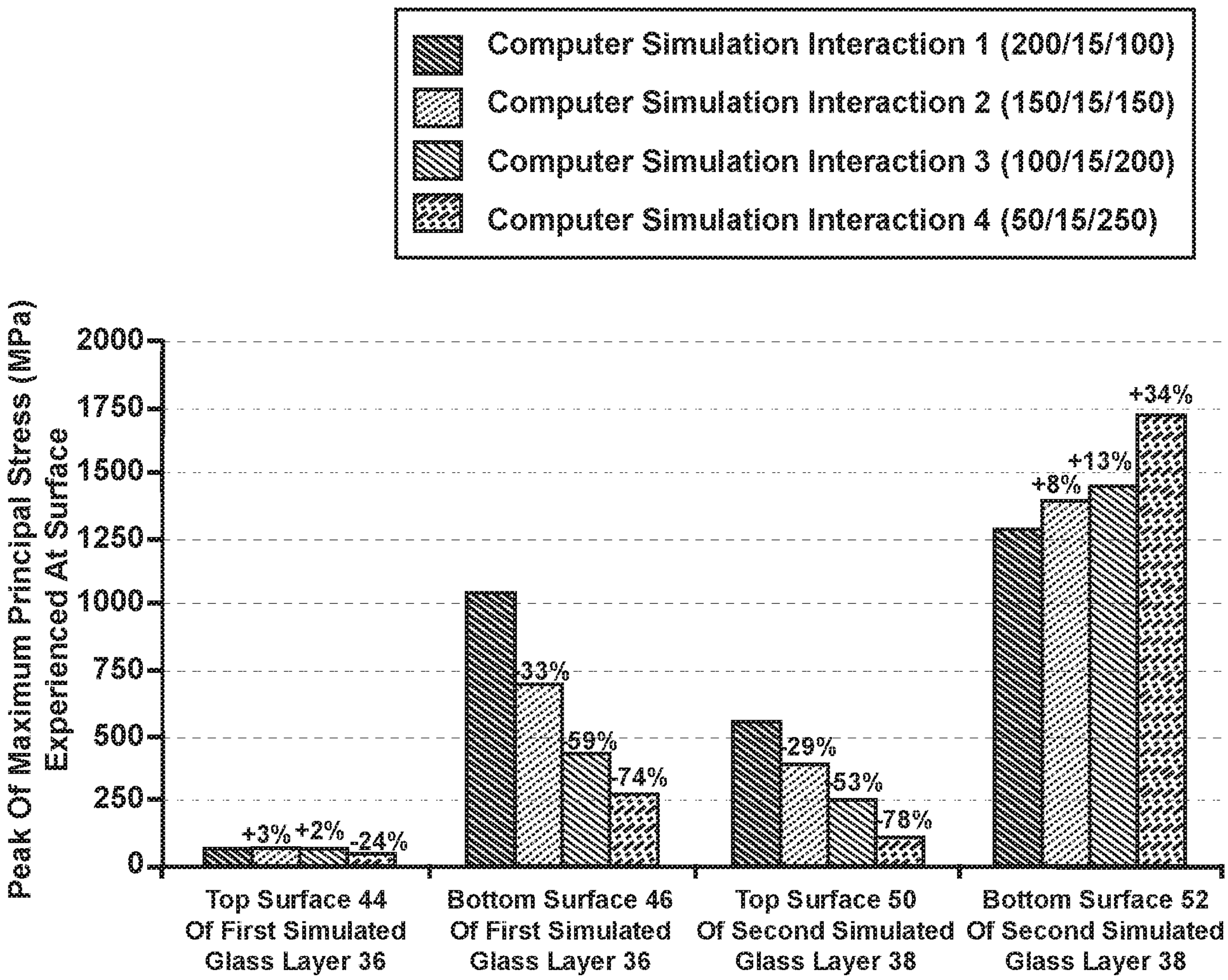

Computer Simulation Interaction 1 (200/15/100)
Computer Simulation Interaction 2 (150/15/150)
Computer Simulation Interaction 3 (100/15/200)
Computer Simulation Interaction 4 (50/15/250)
Maximum Principal Stress (MPa) At Bottom Surface 52 Of Second Simulated Glass Layer 38
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
2
4
6
8
10
Distance Along Path 74 (mm)

FIG. 11



Computer Simulation Interaction 1 (200/15/100)
Computer Simulation Interaction 2 (150/15/150)
Computer Simulation Interaction 3 (100/15/200)
Computer Simulation Interaction 4 (50/15/250)
Peak Of Maximum Principal Stress (MPa) Experienced At Surface
2000
1750
1500
1250
1000
750
500
250
0
+3%
+2%
-24%
-33%
-59%
-74%
-29%
-53%
-78%
+8%
+13%
+34%
Top Surface 44 Of First Simulated Glass Layer 36
Bottom Surface 46 Of First Simulated Glass Layer 36
Top Surface 50 Of Second Simulated Glass Layer 38
Bottom Surface 52 Of Second Simulated Glass Layer 38

FIG. 12

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2019/041825

A. CLASSIFICATION OF SUBJECT MATTER
INV. G06F17/50
ADD.

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)
G06F

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 practicable, search terms used)

EPO-Internal, WPI Data, COMPENDEX, INSPEC, IBM-TDB

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CHEN XUDONG ET AL: "Modelling impact fracture and fragmentation of laminated glass using the combined finite-discrete element method", INTERNATIONAL JOURNAL OF IMPACT ENGINEERING, vol. 112, 14 October 2017 (2017-10-14), pages 15-29, XP085269499, ISSN: 0734-743X, DOI: 10.1016/J.IJIMPENG.2017.10.007	1-14,16, 17
Y	the whole document figures 7, 8, 16 section "4. Numerical examples" page 25, column 2, paragraph 4 table 2 page 25, column 1, paragraph 1 page 22, column 1, paragraph 2 -----	15

-/--

[X] 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	Date of mailing of the international search report
21 October 2019	03/01/2020

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Wellisch, J

1

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	PYTTEL T ET AL: "Failure criterion for laminated glass under impact loading and its application in finite element simulation", INTERNATIONAL JOURNAL OF IMPACT ENGINEERING, PERGAMON, GB, vol. 38, no. 4, 28 October 2010 (2010-10-28), pages 252-263, XP028171468, ISSN: 0734-743X, DOI: 10.1016/J.IJIMPENG.2010.10.035 [retrieved on 2010-11-10]	15
A	the whole document figure 3 page 254, column 2, paragraphs 4, 5 -----	1-14,16, 17
A	D-S KIM AND K-S SHIN ET AL: "P-68: Numerical Modeling of Heat Flow, Deformation and Stress in PDP Module", 2003 SID INTERNATIONAL SYMPOSIUM - MAY 20, 2003, BALTIMORE, MARYLAND, vol. XXXIV, 20 May 2003 (2003-05-20), page 479, XP007008507, the whole document page 2, column 2, paragraph 1 -----	1-17

1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2019/041825

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.:
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:

3. ☐ Claims Nos.:
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:

see additional sheet

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 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.:

1-7, 9, 11(completely); 8, 10, 12-17(partially)

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.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-7, 9, 11(completely); 8, 10, 12-17(partially)

   These claims deal with the optimization of the adhesive thickness for constant glass layer thickness.

   ---

2. claims: 18-20(completely); 8, 10, 12-17(partially)

   These claims deal with mechanical issues related to the class stack, such as specifying glass layer thicknesses and adding a sensor without any limiting reference to optimization

   ---