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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
3 April 2008 (03.04.2008)

PCT

(10) International Publication Number
WO 2008/039471 A2

(51) International Patent Classification:
B32B 37/10 (2006.01)

(21) International Application Number: PCT/US2007/020720

(22) International Filing Date: 26 September 2007 (26.09.2007)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/827,685 29 September 2006 (29.09.2006) US

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(81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, 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, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *without international search report and to be republished upon receipt of that report*

(54) **Title:** MASKING OF AND MATERIAL CONSTRAINT FOR DEPOSITING BATTERY LAYERS ON FLEXIBLE SUBSTRATES

(57) **Abstract:** The present invention relates to masking techniques and apparatuses, and in particular, to a method and apparatus for masking a flexible substrate to be coated with one or more material layers. The method involves flexing a substrate to provide a curved surface and providing a flexible sheet on the curved surface to properly apply a coating on the surface of the substrate. The apparatus includes a substrate and a flexible sheet. An elastic material, such as a spring pin, or an off-axis roll-down bar may be used to create the tension used to flex the substrate and or flexible sheet.

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MASKING OF AND MATERIAL CONSTRAINT FOR DEPOSITING BATTERY LAYERS ON FLEXIBLE SUBSTRATES

RELATED APPLICATIONS

[0001] This application is related to and claims the benefit under 35 U.S.C.§119 of U.S. provisional patent application Serial No. 60/827,865, entitled "Masking of and Material Constraint for Depositing Battery Layers on Flexible Substrates" filed on September 29, 2006, which is incorporated herein by reference in its entirety.

FIELD OF THE INVENTION

[0002] The present invention relates to masking techniques and apparatuses, and in particular, to a method and apparatus for masking a flexible substrate that is to be coated with one or more material layers.

BACKGROUND OF THE INVENTION

[0003] Solid state thin film batteries and other thin film devices often require shadow masking to define the various layers of the battery construction. Typical planar device construction relies on rigid substrate and mask materials and hard edge alignment procedures to register the substrate and mask together. The advent of flexible solid state thin film battery technology and the resultant use of thinner substrate and mask materials, both typically in the form of foils or strips, brings the challenge of constraining these flexible materials. Additionally, the challenge of accurately defining the associated thin film coating area during an application of a typical thin film deposition technique, such as physical vapor deposition or chemical vapor deposition arises. The legacy approach, as shown in Figure 1, is to place a battery substrate 110 into a pocket in a metal plate 115, install a thick rigid mask framework 105 and then constrain this assembly with a clamping mechanism 120. The legacy approach suffers from many issues. For example, the thick rigid masks tend to warp with use and no longer lay flat regardless of the clamping pressure used. Typical vacuum deposition coatings tend to bleed beneath the mask edge thus creating a poorly defined thin film layer edge. Attempts to marry the thin flexible substrates with the legacy equipment suffer because thin flexible substrates and masks rarely lay flat and smooth on a planar surface and thus do not smoothly align against the edges of a defined pocket. This placement error results in a poorly location-registered coating on the surface of the substrate. A poorly location-registered or poorly edge-defined battery layer tends to produce improper battery layer interactions, in these multi-layer battery constructions, with resultant battery failure. The same shortcomings hold true for other thin film devices that typically consist of more than one thin film layer, such as thin film capacitors or transistors.

SUMMARY OF THE INVENTION

[0004] The present invention relates to a method and apparatus for masking a substrate. In one embodiment, the method comprises flexing a substrate to provide a curved substrate surface and providing at least one flexible sheet on the curved surface. The substrate and at least one flexible sheet may be a foil or a strip, for example. In a particular embodiment, the curved surface may be an arc. In another embodiment of the present invention, at least one substrate or sheet, or substrates and sheets, may be provided.

[0005] In one embodiment of the invention, for example, at least one flexible sheet and/or substrate may be placed in tension. The tension may be created by applying force in a direction substantially tangential to the curved surface. In a particular embodiment, the tension may be created by using a spring pin, for example. The spring pin may comprise any of the following, for example: flat leaf spring, bent leaf spring, coil spring loaded pin, formed and/or bent leaf spring, torsion spring, or a tubular spring. In another embodiment, the tension may be created by use of an elastic material, such as a spring member. In a further embodiment, for example, tension may be created by use of an off-axis roll-down bar. Torque may be further used to apply tension to at least one of the substrate and/or flexible material.

[0006] In a further embodiment of the present invention, the tension may, for example, be created independently for each substrate and/or flexible sheet provided.

[0007] Another embodiment of the invention, for example, provides a masking apparatus that includes a substrate holder for securing a flexible substrate in a curved state, and a tensioner for creating a tension in a mask placed over a curved surface of the flexible substrate. In one embodiment, the tensioner may, for example, be a spring pin or an off-axis roll-down bar, for example. The curved state may be an arc, for example.

[0008] Another embodiment of the present invention, for example, provides a method for masking a substrate that includes the steps of providing a substrate, providing at least one flexible sheet on the substrate, and creating tension in at least one sheet or the substrate to form a surface of each sheet into a curved shape. In one embodiment of the invention, the substrate and/or flexible sheet comprises a foil or a strip, for example, and the curved shape is the form of an arc, for example. In an embodiment of the invention, the tension is created by using a spring pin or off-axis roll-down bar, for example.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] Figure 1 is an apparatus for retaining substrates or films in a fixed and flat position (prior art).

[0010] Figure 2 shows a flat, planar retaining structure wherein the substrate and flexible sheets are not in uniform flatness/planarity.

[0011] Figure 3 depicts a holder with a curved surface that provides flexible sheets with a curved surface. It also depicts an embodiment of the present invention wherein the substrate and flexible sheets are tightened by flexing a substrate to provide a curved substrate surface and placing a flexible sheet on the curved surface.

[0012] Figures 4A and 4B are cross-sectional views of embodiments of the present invention wherein a flat leaf spring and a bent leaf spring, respectively, are used to secure the substrate and flexible sheets to a curved surface.

[0013] Figures 5A and 5B are cross-sectional views of embodiments of the present invention wherein a coil spring loaded pin and a formed and/or bent leaf spring, respectively, are used to secure the substrate and flexible sheets to a curved surface. The formed and/or bent leaf spring is shown in Figure 5C.

[0014] Figure 6A is a cross-sectional view of an embodiment wherein a torsion spring is used to secure the substrate and flexible sheets to a curved surface.

[0015] Figures 6B and 6C are cross-sectional views of Figure 6A depicting the ends of the spring which are used to anchor the spring to the curved surface.

[0016] Figures 7A depicts a cross-sectional view of an embodiment wherein a conventional torsion spring is used to secure the substrate and flexible sheets to a curved surface.

[0017] Figures 7 B and 7C illustrate embodiments of a rectangular torsion spring that is used to create tension in the substrate and flexible sheets. The rectangular torsion spring is shown in Figure 7C in greater detail that reveals its wing-type design.

[0018] Figures 8A and 8B depict the use of an elastic material as an embodiment of a spring.

[0019] Figure 9A depicts the use of an embodiment of a tubular spring.

[0020] Figure 9B depicts an embodiment of a tubular spring.

[0021] Figure 9C is a further embodiment wherein the tubular spring element is helical in shape.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0022] It is to be understood that the present invention is not limited to the particular methodology, compounds, materials, manufacturing techniques, uses, and applications described herein, as these may vary. It is also to be understood that the terminology used herein is used for the purpose of describing particular embodiments only, and is not intended to limit the scope of the present invention. It must be noted that as used herein and in the appended claims, the singular forms "a," "an," and "the" include the plural reference unless the context clearly dictates otherwise. Thus, for example, a reference to "an element" is a reference to one or more elements and includes equivalents thereof known to those skilled in the art. Similarly, for another example, a reference to "a step" or "a means" is a reference to one or more steps or means and may include sub-steps and subservient means. All conjunctions used are to be understood in the most inclusive sense possible. Thus, the word "or" should be understood as having the definition of a logical "or" rather than that of a logical "exclusive or" unless the context clearly necessitates otherwise. Structures described herein are to be understood also to refer to functional equivalents of such structures. Language that may be construed to express approximation should be so understood unless the context clearly dictates otherwise.

[0023] Unless defined otherwise, all technical and scientific terms used herein have the same meanings as commonly understood by one of ordinary skill in the art to which this invention belongs. Preferred methods, techniques, devices, and materials are described, although any methods, techniques, devices, or materials similar or equivalent to those described herein may be used in the practice or testing of the present invention. Structures described herein are to be understood also to refer to functional equivalents of such structures. All references cited herein are incorporated by reference herein in their entirety.

[0024] Placing a clean, uniform thin strip or foil of material in tension across a planar, flat surface creates a region of two substantially parallel, non-contacting faces between the strip or foil and the surface. There is no substantial interaction between the tension inducing force vectors and the planar, flat surface and thus no translated downward force is produced. In contrast, a downward force is realized when a tangential force is applied to a thin foil or strip across a curved surface. Simple vector analysis shows a greater downward force is generated even with small radii of curvature. The resultant downward force can be put to beneficial use in creating tight mask-to-substrate interfaces, and thus thin film coatings with well defined edges.

[0025] Referring to Figure 2, the manufacture of thin foils or strips rarely produces uniform and flat bodies. There is typically some error, however minor, that causes a bend deviation 215, 216, 217. For example, foils or strips of material may have cupping, bowing and twisting. In addition, a film layer coated onto such foils or strips may cause an additional bend error. For example, even if a perfectly flat foil or strip of substrate or shadow mask is realized, as the coated layer is grown on the surfaces, stresses inherent to the coating film layer in contact with the surfaces can cause a deformation to occur. More typically, the substrates and masks that must be stacked on top of each other for shadow masking purposes in vacuum deposition processes are bent due to cutting, handling and use. As demonstrated in Figure 2, when a flat surface 205 is utilized for stacking, even when significant tension forces are applied parallel to the plane, it is typically very difficult to cause the foils or strips 215, 216, 217 to lay flat 220. The force needed to cause the foils or strips to lay flat may exceed the yield resistance of the foil or strip material and foil or strip damage may ensue. Figure 3 demonstrates the result 320 of utilizing the translated downward force realized when placing bent foils or strips 315, 316, 317 across a curved surface, such as, for example, arc 310. Testing shows that relatively small amounts of force are necessary to cause such foils or strips to lay flush against each other with such an arrangement in, for example the embodiment of Figure 3.

[0026] In exemplary embodiments, foils or strips of substrate and mask material may be placed in tension across an arc and then fixed in place to maintain the mask to substrate relationship and the location of the substrate to the holder, for example. A simple constraining mechanism for such an arrangement could be a bar across each end of the foils or strips that is constrained by a bolt into the body of an arc-shaped holder. Alternatively, one end of the foils or strips of substrate and mask material may be pinned, clamped, or otherwise fixed in place, tension may be placed on the material from the second end, and while holding that tension the second end may be pinned, clamped or otherwise fixed in place. When fixed in place this pinning or clamping mechanism now maintains the tension on the foils or strips and the external tensioning source may be removed. This simple method may include fixed clamping methods on each end.

[0027] Different materials expand at different rates at different applied temperatures. For instance, typical vacuum deposition processes produce heat in the materials that receive coating. Both the masks and the substrate may be coated in such a process. This resulting temperature change may thus cause non-uniform thermal expansion of the masks relative to the substrates, relative to each other, and/or relative to the holder. Differences in thermal expansion between the materials may also cause surfaces to separate from each other, often resulting in bleeding of the coating beneath the masks. To avoid this issue, an exemplary embodiment may place each foil or strip independently in tension such that the variation in foil or strip length, with thermal expansion, could be accommodated by movement in the tensioning device. There are conceivably many ways to apply the necessary tangential force to these strips of material.

[0028] Some examples of tensioning methods are demonstrated in Figures 4A to 9C. The approaches in Figures 8A and 8B differ somewhat from the approaches shown in Figures 4A to 7C and 9A to 9C because a simple block of memory material, such as rubber, may be used rather than, for example, a metal spring or other tension generating device. Although the examples shown in Figures 4A to 9C show a slot and pin arrangement as a way to engage the tensioning device to the strip of materials that is to be placed in tension, clamping, joining, bonding and other ways could be utilized as well.

[0029] Figure 4A is a cross-sectional view of one embodiment of the present invention wherein a flat leaf spring 430 is fixed to a holder 410 having a curved surface 460 such that a spring force 440 loads a pin 420 to secure the substrate and flexible sheets 415 to a holder 410 having a curved surface 460.

[0030] Figure 4B is a cross-sectional view of one embodiment of the present invention wherein a bent leaf spring 435 is fixed to a holder 410 having a curved surface 460 such that a spring force 445 loads a pin 420 to secure the substrate and flexible sheets 415 to holder 410 having a curved surface 460.

[0031] Figure 5A is a cross-sectional view of one embodiment of the present invention wherein a coil spring 530 loads a pin 520 to secure the substrate and flexible sheets 515 to a holder 510 having a curved surface 560.

[0032] Figure 5B is a cross-sectional view of one embodiment of the present invention wherein a formed 570 and/or bent 580 leaf spring 535 is fixed to a holder 510 having a curved surface 560 such that a spring force loads the formed 570 and/or bent 580 leaf spring 535 to secure the substrate and flexible sheets 515 to a holder 510 having a curved surface 560.

[0033] An embodiment of a formed 570 and/or bent 580 leaf spring 535 is depicted in Figure 5C.

[0034] Figure 6A is a cross-sectional view of one embodiment of the present invention wherein a torsion spring 630 is fixed to a holder 610 having a curved surface 660 such that a spring force loads a pin 620 to secure the substrate and flexible sheets 615 to a holder 610 having a curved surface 660.

[0035] Figure 6B is a cross-sectional view of Figure 6A depicting bent ends 650 of the spring 630 which are used to anchor the spring 630 to a holder 610 having a curved surface 660 and the lengths 640 of the spring 630 which are put in torsion by the substrate and flexible sheets 615 engaged at the pin 620.

[0036] Figure 6C is a cross-sectional view of Figure 6A depicting block ends 655 of the spring 630 which are used to anchor the spring 630 to a holder 610 having a curved surface 660 and the lengths 640 of the spring 630 which are put in torsion by the substrate and flexible sheets 615 engaged at the pin 620.

[0037] Figure 7A is a cross-sectional view of one embodiment of the present invention wherein a conventional torsion spring 730 is loaded to secure the substrate and flexible sheets 715 to a holder 710 having a curved surface 760.

[0038] Figure 7B is a cross-sectional view of one embodiment of the present invention wherein a rectangular torsion spring 735 loads a pin 720 to create tension in the substrate and flexible sheets 715 to secure them to a holder 710 having a curved surface 760.

[0039] Figure 7C reveals the wing-type design of the torsion spring of Figure 7B depicting spring ends 750 of the spring 735 which are used to anchor the spring 735 to a holder 710 having a curved surface 760 and the lengths 740 of the spring 735 which are put in torsion by the substrate and flexible sheets 715 engaged at the pin 720.

[0040] Figure 8A is a cross-sectional view of one embodiment of the present invention wherein an elastic material 830 is embedded in the top of a holder 810 with a curved surface 860 such that a spring force loads the pin 820 to secure the substrate and flexible sheets 815 to a holder 810 having a curved surface 860.

[0041] Figure 8B is a cross-sectional view of one embodiment of the present invention wherein an elastic material 830 is embedded in the bottom of a holder 810 having a curved surface 860 such that a spring force loads the pin 820 to secure the substrate and flexible sheets 815 to a holder 810 having a curved surface 860.

[0042] Figure 9A is a cross-sectional view of one embodiment of the present invention wherein a tubular spring element 930 is fastened to a pin 920 to secure the substrate and flexible sheets to a holder 910 with a curved surface 960.

[0043] Figure 9B reveals the cut-away portions 931, 932 of the tubular spring 930 of Figure 9A and the pin 920 which may be welded, soldered, brazed, pressed in or peened to the tube.

[0044] Figure 9C is a further embodiment which reveals a helical cut-away 931, 932 design of the tubular spring element 930 of Figure 9A and the pin 920 which may be welded, soldered, brazed, pressed in or peened to the tube.

[0045] In particular, although the examples shown in Figures 4A to 7C and 9A to 9C show a spring pin arrangement to keep the strip of materials in tension over the curved surface of the substrate, an off-axis roll-down bar could be utilized as well, for example.

[0046] The presented embodiment of a masking approach enables the use of less expensive masking materials. For example, thin foils or strips of raw material are typically cheaper to procure and less time consuming and labor intensive to convert to the necessary mask openings than machining thicker blocks of the same material. Also, thin foils or strips lend themselves to more cost-effective forms of conversion like laser and water jet cutting, etching, die-cutting, shearing and stamping.

[0047] With the bottom surface of a substrate foil or strip held uniformly against an arc-shaped holder, the resulting conductive cooling in a typical vacuum deposition process may be more uniform than with a flat holder. This exemplary process facilitates consistent film growth, deposition rates and properties across the entire coating area, and thus more consistent battery product performance.

[0048] Without departing from the spirit and scope of this invention, one of ordinary skill in the art can make various changes and modifications to the method and apparatus of the present invention to adapt it to various usages and conditions. For instance, although the above describes exemplary methods and apparatuses for masking a flexible battery, it is to be understood that the present invention can be used in a variety of applications, such as thin film electronic devices, and non electrical devices, such as used for graphical design. Additionally, device substrates need not be flexed to produce the curved surface. For example, a device substrate to which a mask is applied can be curved by design and manufacture. As such, these and other changes and modifications are properly, equitably, and intended to be, within the full range of equivalents of the following claims.

What is claimed is:

1. A method for masking a substrate, comprising:

flexing at least one substrate to provide a curved substrate surface; and

providing at least one flexible sheet on said curved surface.

2. The method of claim 1, wherein said substrate comprises a foil or a strip.

3. The method of claim 1, further comprising providing said curved surface in the form of an arc.

4. The method of claim 1, wherein said flexible sheet comprises a foil or strip.

5. The method of claim 1, further comprising placing said at least one sheet in tension.

6. The method of claim 1, further comprising placing said at least one substrate in tension.

7. The method of claim 5, further comprising applying a force to said at least one sheet in a direction substantially tangential to the curved surface.

8. The method of claim 7, further comprising using a mechanism selected from the group consisting of a spring pin and an off-axis roll-down bar.

9. The method of claim 6, further comprising applying a force to said at least one substrate in a direction substantially tangential to the curved surface.

10. The method of claim 9, further comprising using a mechanism selected from the group consisting of a spring pin and an off-axis roll-down bar.

11. The method of claim 1, further comprising creating tension by applying torque to said at least one substrate.

12. The method of claim 1, further comprising applying a torque to said at least one sheet.

13. A masking apparatus, comprising:

a substrate holder for securing a flexible substrate in a curved state;

a tensioner for creating a tension in a mask placed over a curved surface of the flexible substrate.

14. The apparatus of claim 13, wherein said tensioner comprises:

at least one engaging member that engages with said sheet and is adapted to apply a force in a direction tangential to said curved surface.

15. The apparatus of claim 13, wherein said tensioner is selected from the group consisting of a spring pin and an off-axis roll-down bar.

16. The apparatus of claim 13, wherein said curved state is an arc.

17. The apparatus of claim 13, wherein said tensioner is adapted to apply tension to said substrate.

18. A method for masking a substrate, comprising:

providing at least one substrate;

providing at least one flexible sheet on said substrate; and

creating tension in said at least one sheet or substrate to form a surface of each sheet into a curved shape.

19. The method of claim 18, further comprising applying force to said at least one sheet in a direction substantially tangential to the curved surface.

20. The method of claim 18, further comprising applying force to said at least one substrate in a direction substantially tangential to the curved surface.

21. The method of claim 18, wherein said substrate comprises a foil or a strip.

22. The method of claim 18, further comprising providing said curved shape in the form of an arc.

23. The method of claim 18, wherein said flexible sheet comprises a foil or a strip.

24. The method of claim 18, further comprising applying a torque to the at least one substrate.

25. The method of claim 24, further comprising using a mechanism selected from the group consisting of a spring pin and an off-axis roll-down bar.

PRIOR ART

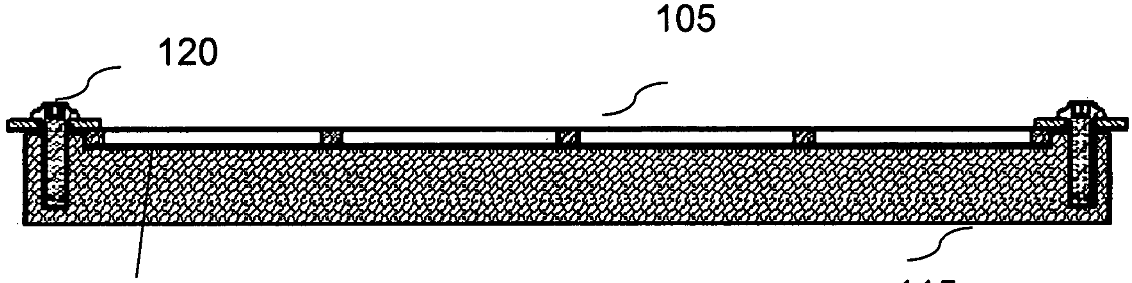

Figure 1

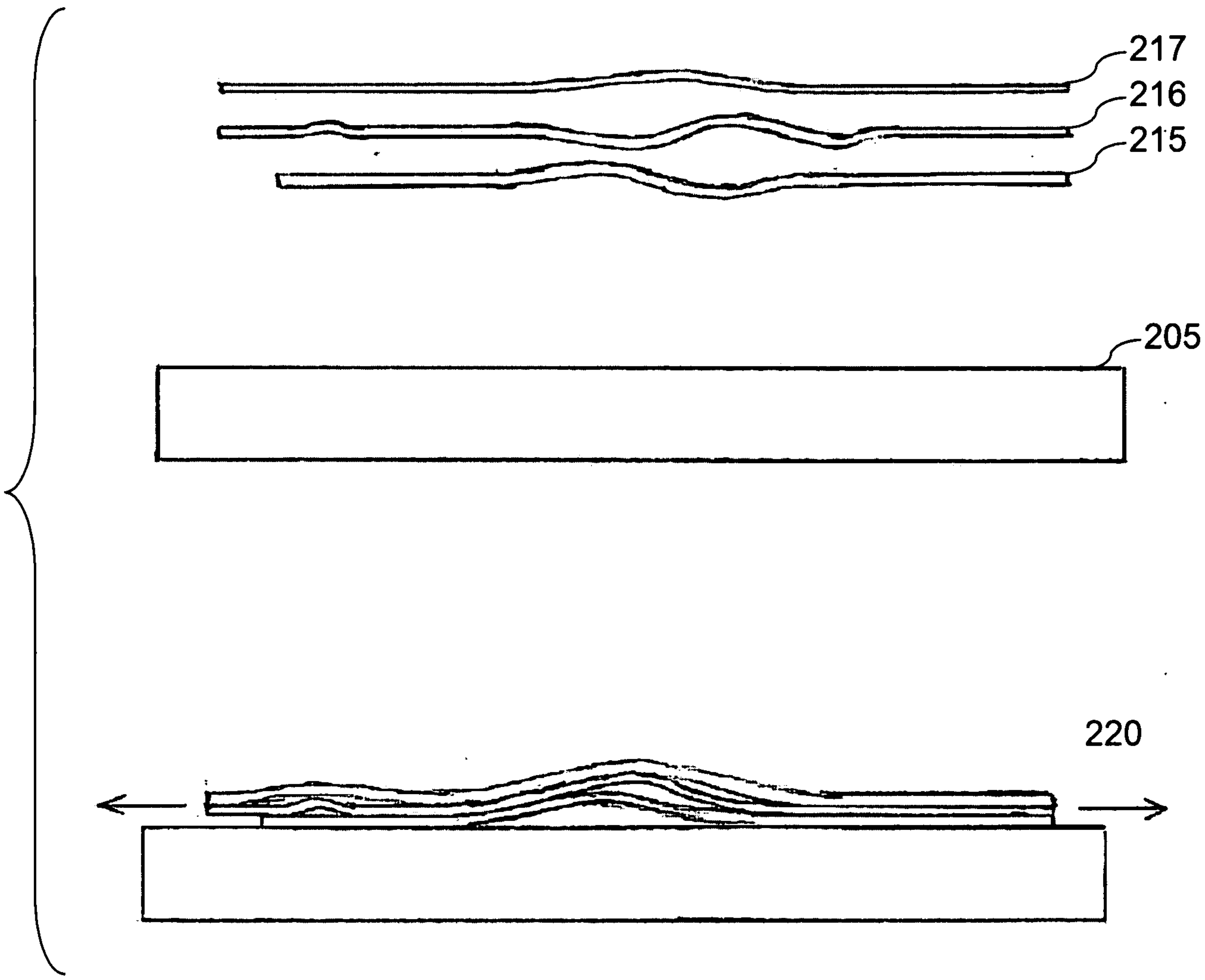

Figure 2

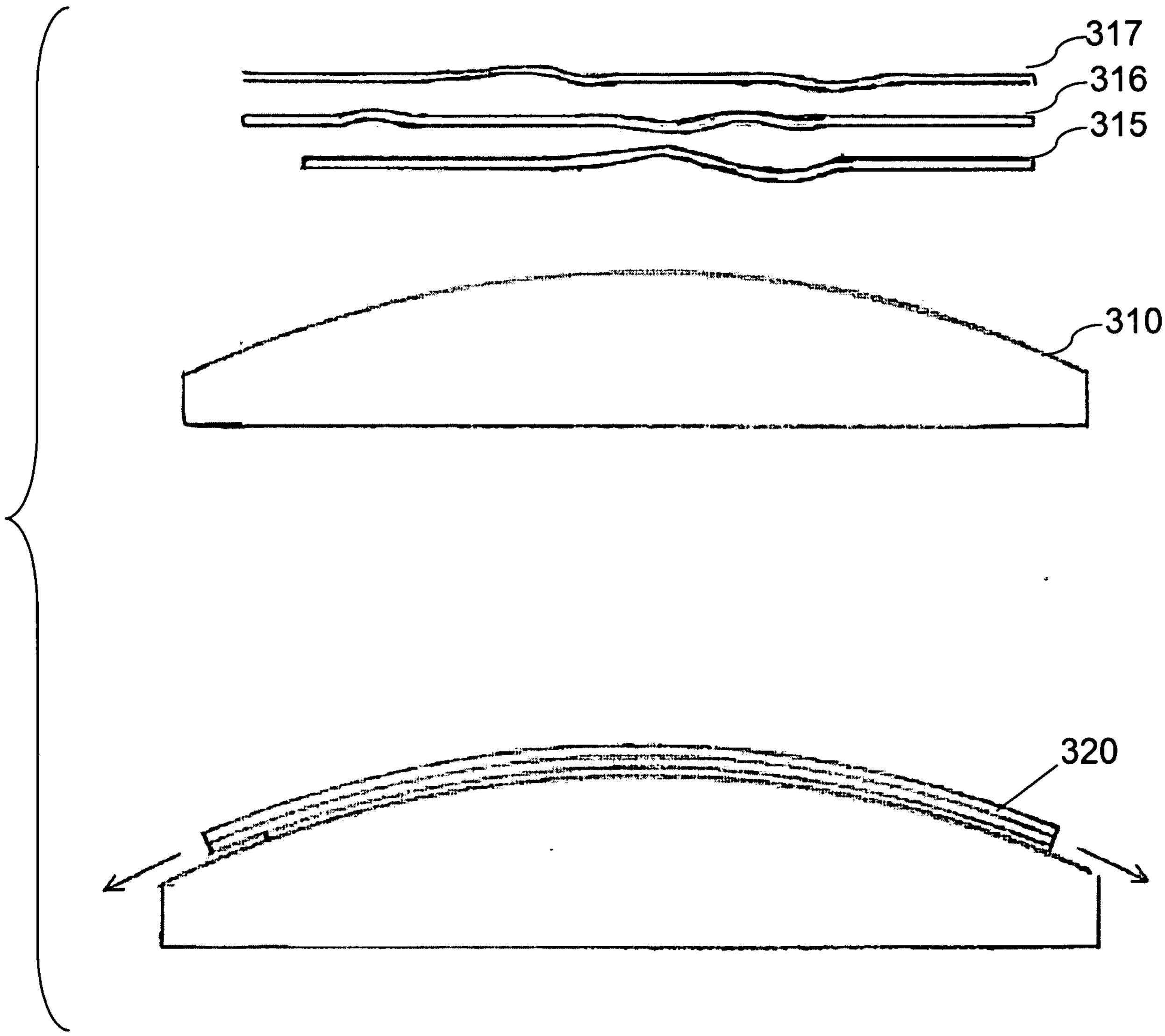

Figure 3

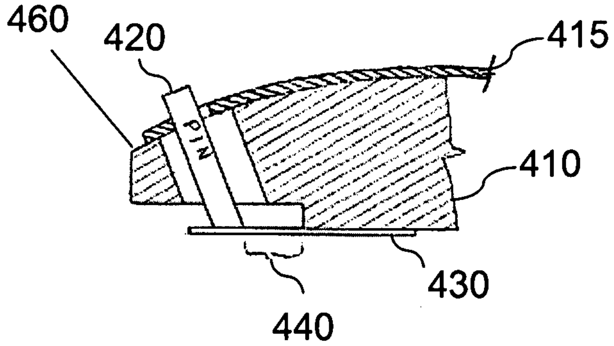

Figure 4A

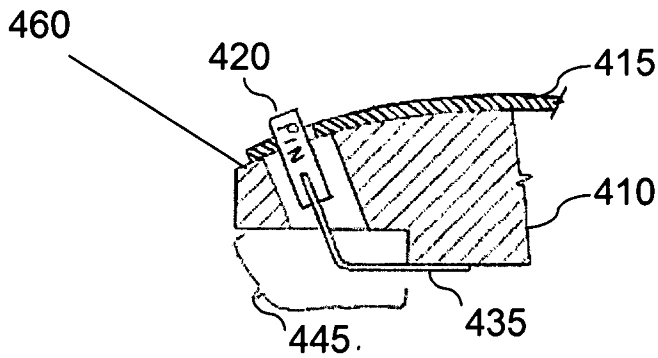

Figure 4B

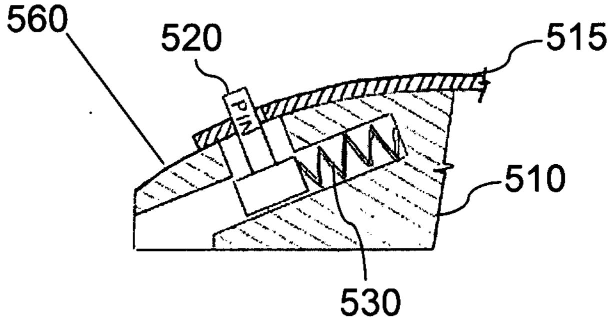

Figure 5A

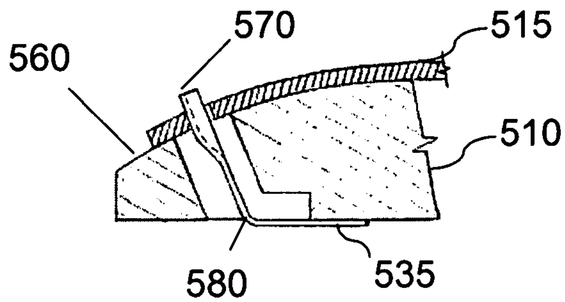

Figure 5B

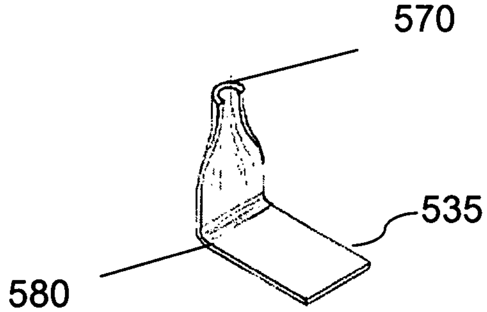

Figure 5C

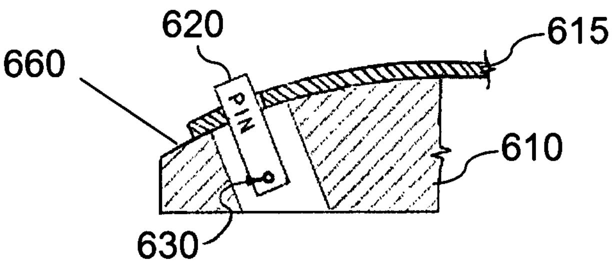

Figure 6A

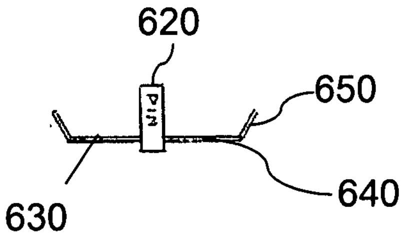

Figure 6B

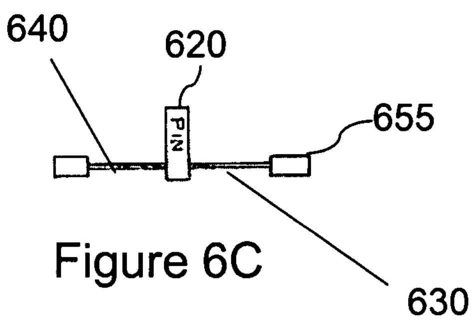

Figure 6C

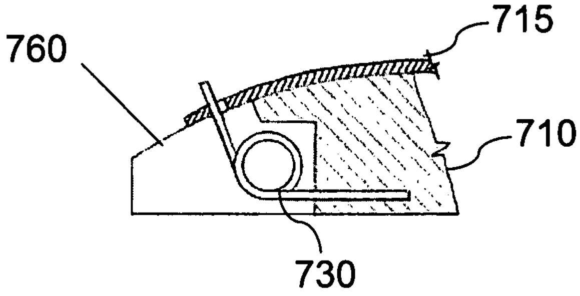

Figure 7A

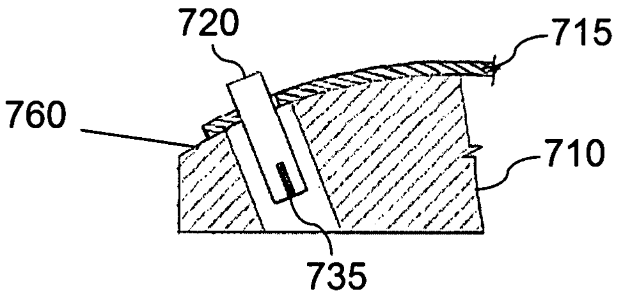

Figure 7B

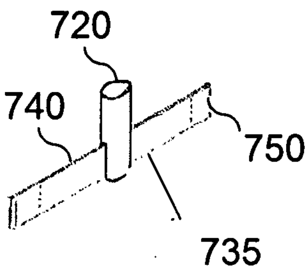

Figure 7C

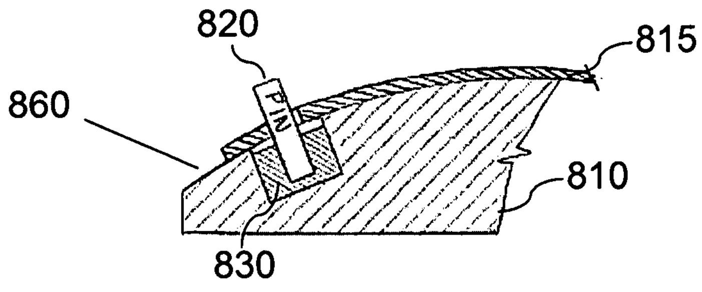

Figure 8A

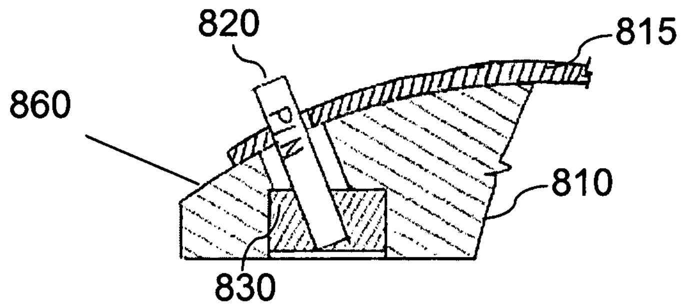

Figure 8B

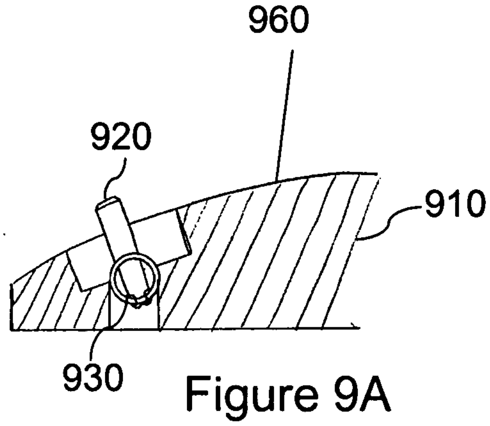

Figure 9A

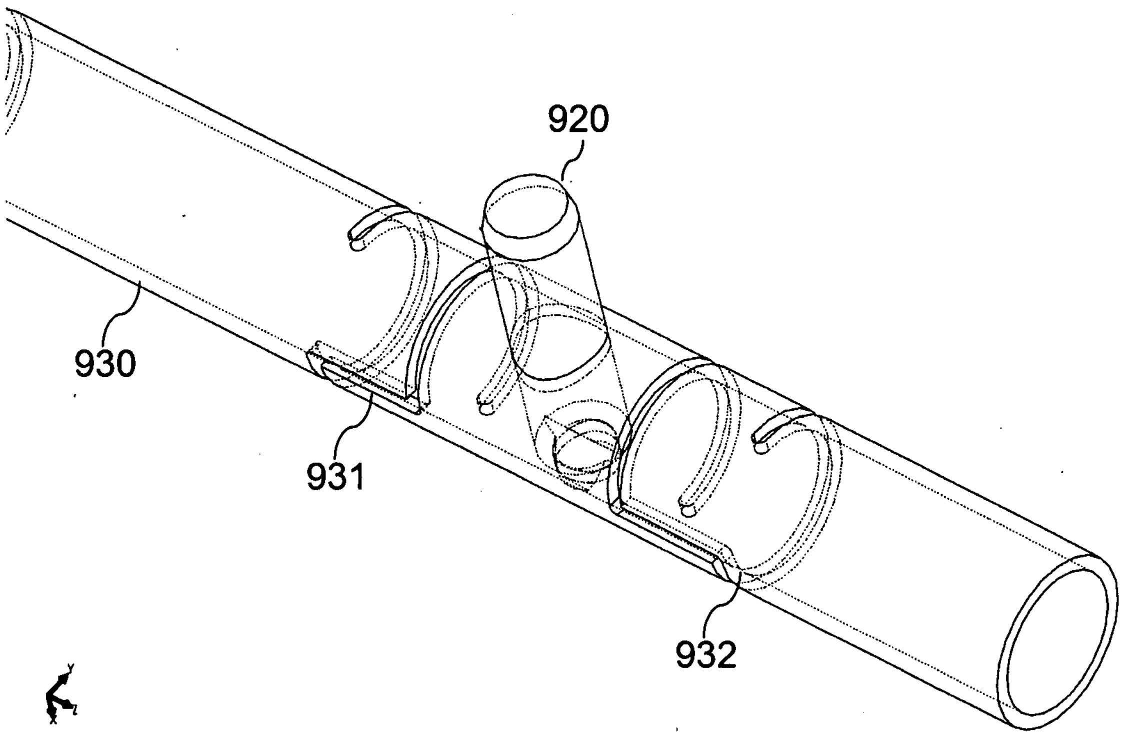

Figure 9B

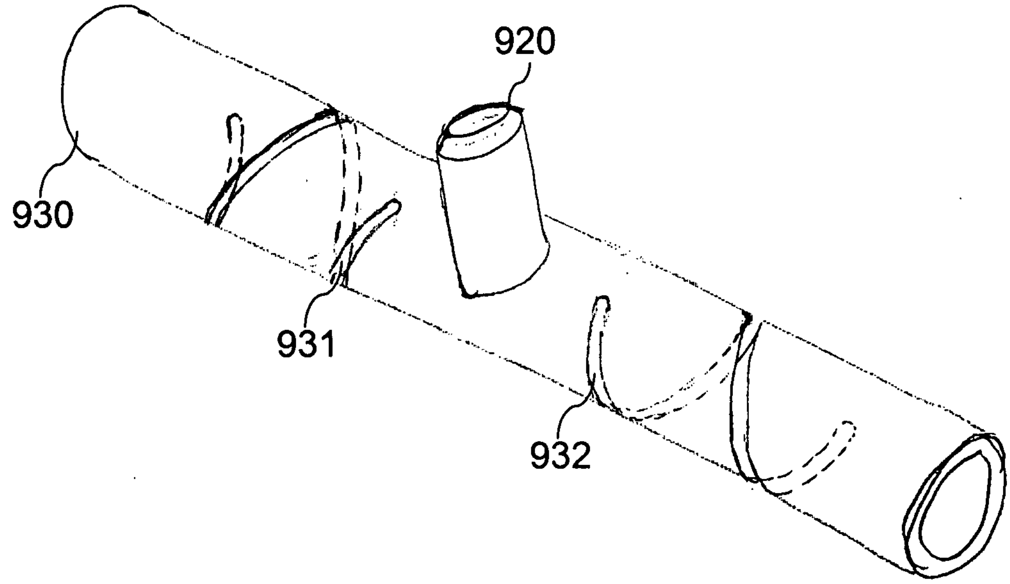

Figure 9C